INDISPOL – An Interactive Package for Predicting Atmospheric Dispersion of Pollutants

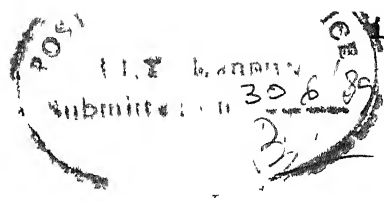
A Thesis Submitted
In Partial fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

by
RAJESH PRASAD

to the
DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
JUNE, 1989

To,

My parents



CERTIFICATE

Certified that the work presented in this thesis entitled "*INDISPOL -an Interactive Package for Predicting Atmospheric Dispersion of Pollutants*" by *Mr Rajesh Prasad* has been carried out under our supervision and has not been submitted elsewhere for a degree

Dipak Ghosh
Assistant Professor

Vinod Tare
Assistant Professor

Department of Civil Engineering
Indian Institute of Technology Kanpur

June 1989

ACKNOWLEDGEMENT

It's my great pleasure to express thanks to my guides Dr Vinod Tare and Dr D K Ghosh. I must express my hearty gratitude and deep regard to Dr Tare for his most invaluable guidance, help, interest and encouragement.

My sincere regards are due to Drs A V S Prabhakara Rao, Malay Chaudhuri, C Venkobackar, and (Mrs) Leela Iyengar.

Thanks are also due to to my wing mates - Raju Bhaiya, Bhagvat, Seshadri, Jha, Raman, Vishnu, DK, AQ, Vats, Sen, Sanjay and my class-mates - Funkwal, Jawed and Vijay.

I am grateful to S K Rakesh and his wingmates, Anil, Sallabh, and Suman for their help.

I wish to extend sincere gratitude to my parents, brothers and sisters for their encouragement and love.

I wish to express my appreciation to Mr S K Khullar for his nice typing and very friendly relations.

Rajesh

CONTENTS

LIST OF FIGURES

NOMENCLATURE

a	constant used in σ power law (Eqs 5.14, 5.15)
b	constant used in σ power law (Eqs 5.14, 5.15)
c	constant used in σ power law (Eq 5.15)
	point concentration of pollutant, $M\ L^{-3}T^{0}(\mu g/m^{3})$
CPX, CPY, CPZ	element coordinates, $M^{0}L\ T^{0}(m)$
d	constant used in σ power law (Eq 5.15)
dA	elemental area normal to x plane, $M^{0}L\ T^{0}(m)$
d_{V_H}	virtual horizontal distance, $M^{0}L\ T^{0}(m)$
d_{V_z}	virtual vertical distance, $M^{0}L\ T^{0}(m)$
D	direct distance of a point on plume from the source, $M^{0}L\ T^{0}(m)$
	direct distance between the puff and the receptor, $M^{0}L\ T^{0}(m)$
D_1	distance between the leading point of a segment and the receptor, $M^{0}L\ T^{0}(m)$
D_2	distance between the trailing point of a segment and the receptor, $M^{0}L\ T^{0}(m)$
D_H	horizontal component of advection in Δt, $M^{0}L\ T^{0}(m)$
D_s	stack diameter, $M^{0}L\ T^{0}(m)$
EFL	effective length of an element, $M^{0}L\ T^{0}(m)$
f	constant used in σ power law (Eq 5.15)
h_p	height of puff centre point above ground level $M^{0}L\ T^{0}(m)$

H	effective plume/stack height, $M^0 L\ T^0$ (m)
H_s	stack height, $M^0 L\ T^0$ (m)
IFS	index of the leading point of an element
ISS	index of the trailing point of an element
K	chemical transformation factor $M^0 L^0 T^{-1}$ (%/hr)
M	mass of the pollutant contained in the element, $M\ L^0 T^0$ (μg)
p	constant used in σ power law (Eq 5.14)
P_1	dry deposition, $M^0 L^0 T^{-1}$ (%/hr)
P_2	wet deposition, $M^0 L^0 T^{-1}$ (%/hr)
P_r	current precipitation rate at element's location, $M^0 L\ T^{-1}$ (mm/hr)
P_{ref}	fraction reflection from the surface
P_{σ_y}	σ_y at the centre of an element (puff), $M^0 L\ T^0$ (m)
P_{σ_z}	σ_z at the centre of an element (puff), $M^0 L\ T^0$ (m)
q	constant used in σ power law (Eq 5.14)
Q	pollutant source strength/emission rate, $M\ L^0 T^{-1}$ (μg/s)
Q_h	heat emission rate, $M\ L^2 T^{-3}$ (KJ/s)
Q(t)	pollutant's current emission rate, $M\ L^0 T^{-1}$ (μg/s)
R	stability parameter in power law expression for velocity (Eq 5.13) receptor
R'	base of the perpendicular drawn from a receptor on the centre line of the closest segment
S	pollutant scavenging ratio

SL,SM,SN	direction cosines of the centre line of an element
SXR, SYR SZR	coordinates of R', $M\ L^0T^0$(m)
S_{σ_y}	σ_y a R', $M^0L\ T^0$(m)
S_{σ_z}	σ_z at R', $M^0L\ T^0$(m)
t	time, M^0L^0T(s)
t_v	virtual age of an element, M^0L^0T(s)
t_{V_H}	horizontal virtual age of an element, M^0L^0T(s)
t_{V_z}	vertical virtual age of an element, M^0L^0T(s)
T	projection of the line joining receptor to the trailing point of the closest segment on its centre line, M^0L^0T(m)
T_p	current thickness of precipitation layer at element's location, $M^0L\ T^0$(m)
u or U	wind velocity, $M^0L\ T^{-1}$(m/s)
u_1	wind velocity at height z_1, $M^0L\ T^{-1}$(m/s)
u_2	wind velocity at height z_2, $M^0L\ T^{-1}$(m/s)
U_{min}	minimum wind velocity, $M^0L\ T^{-1}$(m/s)
u_s	wind velocity at stack height, $M^0L\ T^{-1}$(m/s)
$\bar{u}$	turbulent wind velocity, $M^0L\ T^{-1}$(m/s)
$\bar{u}'^2$	mean square of eddy velocity component in x direction, $M^0L^2T^{-2}$(m/s)^2
$\vec{U}$	wind velocity vector, $M^0L\ T^{-1}$(m/s)
v	component of wind velocity in y direction, $M^0L\ T^{-1}$ (m/s)

V_i	current pollutant deposition velocity at element's location, $M^0L\ T^{-1}$(m/s)
V_s	stack gas exit velocity, $M^0L\ T^{-1}$(m/s)
w	component of wind velocity in z direction, $M^0L\ T^{-1}$(m/s)
w'	component of eddy velocity in z direction, $M^0L\ T^{-1}$(m/s)
$\bar{w'^2}$	mean square of eddy velocity component in z direction, $M^0L\ T^{-1}$(m/s)
x	d/w distance, $M^0L\ T^0$(m)
XR,YR,ZR	receptor coordinates, $M^0L\ T^0$(m)
y	crosswind distance $M^0L\ T^0$(m)
z	vertical distance $M^0L\ T^0$(m)
ΔC	concentration contribution by one surce to the receptor, $M\ L^{-3}T^0$($\mu g/m^3$)
	concentration contribution by a puff, $M\ L^{-3}T^0$ ($\mu g/m^3$)
ΔH	plume rise, $M^0L\ T^0$(m)
Δ_{met}	duration for which meteorology is assumed constant, M^0L^0T(min)
Δt	element generation time step, M^0L^0T(min)
ΔZ	vertical thickness of an element (puff) = $2\sigma_z$, $M^0L\ T^0$(m)
σ_y	dispersion standard deviation at a d/w distance in c/w direction, $M^0L\ T^0$(m)
σ_z	dispersion standard deviation at a d/w distance in vertical direction, $M^0L\ T^0$(m)

ABSTRACT

The present work is an attempt to develope a PC based interactive package for predicting dispersion of pollutants emitted from point source(s) in the atmosphere The package is written in TURBO PASCAL version 4 0 to provide graphic visual and to achieve user machine interaction The selection is achieved through a screen menu using arrow keys (→ ↑ ← ↓) on the keyboard The package also provides facilities to have access to any word processing software (WORDSTAR 2000 currently implemented) to edit/create input/output files at appropriate levels

The menus are divided into two levels and the menu applicable at a particular stage of operation is displayed The selections made are displayed simultaneously indicating the path through which an individual terminal selection is identified When a selection is being made OPTION ON is displayed while at the end of selection READY ==> is displayed which permits continuing with the current selection, making additional selection, printing the screen display or termination of the package as may be desired The package initialization and execution starts by giving command INDISPOL On line HELP and GUIDE are available for package operation and making appropriate selections respectively

The simulation models employed for dispersion of pollutants are classified into five categories, UNIS for single, steady and continuous point source; MULTYS for steady and multiple continuous point sources; PUFFS for fluctuating point emissions in calmwind condition; SEGMNT for fluctuating point emissions in transport condition, and PUFSEG for fluctuating point emissions in lightwind conditions UNIS and MULTYS assume stationary and homogeneous atmosphere and use Gaussian approach PUFFS, SEGMNT and PUFSEG consider non-stationary and inhomogeneous atmosphere and use extended Gaussian approach

The package structure provides facilities for both digital as well as graphical output However, the current version supports graphical facilities for UNIS only

KEYWORDS

Air pollution, atmospheric dispersion, Gaussian diffusion, non-stationary atmosphere, inhomogeneous atmosphere, puff, segmented plume, mixed puff-segment approach, short-term emissions, unsteady-state conditions, computer software, MS DOS, Turbo pascal, interactive package, interactive graphics, personal computers, IBM compatible

1 INTRODUCTION

An effective protection of our environment is highly dependent on precise information on its state and development In this way, computer use in environmental agencies has been gaining more and more importance However, as a scientific application field, environmental computing was only of limited research interest till now Just recently an increasing research interest can be observed as evident by intensified national and internatinal publishing (e g ENVIROSOFT journal) and recent conferences including the ongoing ENVIROSOFT-series

In general, different functional application fields for computers in environmental management can be stated as follows

Data collection/measuring (e g measuring of air pollutants in air quality monitoring systems)

Data storage and retrieval (e g environmental research project or literature databases with flexible search functions)

Data analysis (e g estimation of emissions from computerised emission registers)

Modelling and simulation (e g propagation calculations for air or water pollutants)

Graphics (e g land use mapping)

A survey report (Page, 1988) indicate that computers are mainly employed for data processing (77% applications) while modelling and simulation applications are only 12% On the system technical side, the study (Page, 1988) revealed a dominance of main frame programs (more than 50%) which are run on inhouse machines or in community centres The PC-use in environmental computing, however, is catching up (more than 20%) The predominant programming lanauge is still FORTRAN (45%), modern lanauges such as PASCAL or the database languages are not yet very common (10%) The statistics of the number of users per programme shows that environmental software is only used by minority of the

staff in environmental offices (45% of the programmes with maximum 5, only 5% with more than 10 regular users) This may be due to the availability of limited number of PC based user friendly or interactive packages, particularly in the field of modelling and simulation

Modelling and simulation of environmental problems hold a long tradition (Frenkiel and Goodall, 1978) The software techniques used in environmental modelling, however, are not always on a satisfactory level from the user point of view User friendly or interactive software can offer powerful concepts for supporting design, implementation and operation of models which are not yet sufficiently used in environmental modelling These software concepts provide a high degree in flexibility and use adapation in running environmental analysis methods and models Interactive modelling and simulation systems are mainly concerned with computer support of the entire process of model building and simulation, from planning, to building, and documentation of models upto graphical presentation Through a high degree of interactivity on all system levels interactive (graphical) modelling directly at the display, interactive control of simulation flow as well as interactive preparation of simulation results is offered The aim is a high degree of friendliness in computer modelling particularly for users with little or no computer experience The main asset of this modelling tool is its object oriented user interface taking advantage of modern graphical features such as windows, pull down menus, etc

Concepts of interactive modelling and simulation are not only relevant for scientific dispersion modelling, but also for Decision Support Systems in planning and policy making Hence, the major thrust in the present study is laid on developing an interactive package for simulation of dispersion of pollutants in the atmosphere

2 STATE OF THE ART ON DISPERSION MODELLING

2.1 General

In environmental science, as in most of the fields of applied scinces, the main interest lies in cause and effect relationships or in casual explanations of events The desire for this knowledge stems from a need to know what actions (causes) must be taken to achieve a particular change (effect) in environmental quality In philospher Karl Popper's words (Popper, 1959) "*casual explanations of any event require two ingradients universl statement, which are hypotheses of the character of natural laws, and singular statements, which pertain to the specific event in question It is from the set of these two types of statements that singular statements or specific predictions about events are deduced*"

It is obvious that atmospheric motion plays a major role in air pollution phenomena As such attempts must be made (1) to formulate new/evaluate existing universal mathematical statement(s) about the character of this role, and (2) to know how these statements in conjunction with meteorological observations ultimately affect both the form of the dispersion model and the types of predictions that can be made The meaningful use of air pollution models of universal statements as a tool in decision making process requires both an understanding of the inherent limits of model capabilities and some measure of uncertainty associated with a particular model's predictions Thus in formulating/evaluating/selecting a dispersion model consideration must be given to the analysis of model's capabilities, uncertainties and simplicity

2.2 Basic Framework for Dispersion Modelling

It is well known that the dispersion of gaseous and particulate material released into the atmosphere is dependent on turbulent and convective motions present within the boundary

layer The turbulent motion arises because of the physical properties of the material, the vertical temperature structure and the effect of ground roughness elements where the drag on the surface is balanced by momentum transmitted through the layer by shearing stresses

The fundamental problem of turbulent motion (diffusion), both practically and theoretically, is to predict the variations with space and time of the statistical properties associated with the distribution of concentration of contaminant in a cloud containing a finite quantity of material Although there have been notable success on the theoretical side, there are formidable difficulties preventing a complete solution So prediction in practical cases has still, unfortunately, to be made using empirical assumptions, not justified by (or even consistent with) theory This is ultimately unsatisfactory Even though the use of such assumptions leads to reasonable predictions in some, even many cases, the basic physics is avoided Thus there is no way of assessing the magnitude of errors involved, which experiments show can be very large Nor does such a procedure help in establishing a sure framework for practical predictions, which is definitely the ultimate goal of all research in atmospheric diffusion

The understanding and modelling of plume dispersion downwind of point and line sources in turbulent boundary layers has been hampered by a lack of experimental information concerning the terms occuring in the exact transport equations for the mean concentration, the scalar fluxes and the scalar fluctuations Development of the subject by way of experiments conducted in the atmosphere has been limited by the complexities of atmospheric boundary layer flows and, in addition, the instrumentation and resources necessary to undertake sufficiently detailed experiments have generally not been available

The problem of turbulent diffusion in the atmosphere has not yet been uniquely formulated in the sense that a single basic physical model capable of explaining all the significant aspects of the problem has not yet been proposed There are three

alternative approaches based on statistical, similarity and gradient transfer theories (Nema, 1987; Robins and Fackrell, 1979; Swadas, 1974) None of these can be categorically eliminated from consideration since each one has its own importance

A mathematical model of atmospheric dispersion must attempt to simulate the gross behaviour of plumes emitted from ground or elevated sources Although several basic aforementioned approaches are possible, usually a number of simplifying assumptions are necessary in any case to obtain a mathematically tractable solution As a result, all these theories tend to the same distribution function for the pollutant concentration Mathematically this means that the concentration in the crosswind and vertical directions may be 'normally' distributed Hence, the most widely accepted model at present is the Gaussian plume model which does exhibit "normal" distribution as suggested by the three basic theories

The Gaussian diffusion model has achieved considerable popularity among people attempting to describe the role of atmospheric dispersion The ease of application of this model for conservative pollutants out-weights its shortcomings as a complete mathematical description of the diffusion process Most measured dispersion data fit the Gaussian model reasonably well (Bowne, 1974) and published dispersion coefficients have been available for considerable length of time (Pasquill, 1974)

2 3 Recent Developments in Dispersion Modelling

Extensive work has been done in recent years on air pollution dispersion modelling and as a result large number of publications are available However, none of these publications suggest a fundamentally new approach to the problem of dispersion modelling and most of them stem from the basic three approaches mentioned in the previous section The major contribution is in terms of improved idealization of source, atmosphere/terrain characteristics (e g Krogstad and Patterson, 1986; Zannetti, 1984, Sheih, 1978) or providing algorithms to solve dispersion equations employing numerical techniques (e g Enger, 1986; van

Stijn and Nieuwstadt, 1986) or developing analytical solutions of diffusion equatons under specialized conditions (e g Shukla and Chauhan, 1986) In spite of the aforementioned improvements and expansions, it has been found that often the more complex methodologies possess only a theoretical (or potential) capability of better representing the complexities of the real world (Lamb, 1984) Zannetti (1986) after reviewing recent important model validation studies concludes that

"*when the models are applied in an operational, 'hands off' manner short-term modelling simulations are substantially inaccurate with errors of a factor of two in more than 50% of the cases, the more complex modelling approaches do not provide a substantial improvement in reproducing reality, compared with the more simple ones*"

Thus there is a need of additional air pollution modelling efforts for improving the present simulation capabilities and allowing the models to reach the level of performance that is expected from them, especially for regulatory applications since air pollution dispersion models are the only tool for inferring a quantitative deterministic relation between anthropogenic pollutant emissons and ambient concentrations Zannetti (1986) presented a new methodology to simulate complex dispersion conditions in both transport and calmwind situations while maintaining the simplicity of the basic Gaussian equation The method is claimed to be computationally cost effective and allows a non-stationary, inhomogeneous representation of atmospheric phenomena such as transport, turbulent diffusion, dry and wet deposition, and first order reaction chemistry This new approach, called "mixed Puff-Segment approach", appears to provide an improved simulaion tool for practical applications in both short-range and long-range air pollution dispersion studies, in either flat or complex terrain

In general, atmospheric dispersion is but one of the large class of phenomena which are composed of a deterministic and random element The deterministic component may be modelled with all the precision allowed by experimental input while the random, stochastic part is unpredictable Randomness in atmospheric modelling appears in two forms 1 the input error, as the initial

state can never be defined without error and with (almost) infinite definition, 2 the random choices available to the system during its evolution

In any system there exists an unequivocal chain between an effect and the cause In many cases it may be a straight forward process to describe the link between cause and effect by a mathematical expression (= model) The formula may sometimes be a very complex one, but there is always an equation (or a system of many equatons) relating to the effect to the cause The chain between cause and effct is uninodal In atmospheric dispersion this chain is multi-nodal The more sophisticated the dispersion calculation, the more nodes are present A "simple" Gaussian real-time plume calculation contains atleast the following nodes (Benarie, 1987) 1 to 4, source specifications (emission intensity, concentration, exhaust velocity, temperature), 5 to 12, meteorological parameters (position coordinates, wind velocities and their fluctuations in three coordinate directions, temperature, stability), 13 and 14, the dispersion parameters (σ_y and σ_z), 15 pollutant loss (deposition) or formation parameter Assuming very optimistically error of 3% at each node, the end result will be erroneous by about 12 to 50% But if the error at each node is a still modest 10%, the outcome will be uncertain by about 40 to 400% (Benarie, 1987) And all this with a physical formula which is considered as correct

In spite of the aforementioned inherent limitations one has to resort to dispersion modelling because this is the only tool for inferring a quantitative deterministic relation between pollutant emissions and ambient concentrations Thus there is a need to continue air pollution modelling efforts for improving the present simulation capabilities

3 SCOPE OF THE PRESENT WORK

The main thrust in the present work has been on developing an interactive package which can be implemented on any IBM PC or its compatible to simulate pollutant dispersal from single or multiple, continuous or short term, steady or fluctuating, surface or elevated source(s) in stationary or non-stationary, homogeneous or inhomogeneous atmosphere The package is aimed at providing facilities for (1) flexible system of selection of simulation procedure through which the user can nevigate with ease, (2) acceptance of input data through terminal or a file created in the users area, (3) checking of input data and editing of input files, (4) guidelines for selection of simulation models implemented, (5) built-in procedures for stability classification and evaluation of dispersion parameters in the absence of user specifications, and (6) display and storage of output in graphical as well as digital form The development of a package which will have aforementioned facilities involves following steps

1 Selection of appropriate simulation procedure(s) for atmospheric dispersion of pollutants

2 Selection of programming language which can support required graphic capabilities

3 Selection of proper software environment and supporting software packages to facilitate efficient utilization of a PC

4 Developing package programme algorithm and its implementation

Selection of appropriate simulation technique is a very difficult task Development in atmospheric dispersion modelling techniques in the last two decades has been quite remarkable With the parallel growth in computational capabilities, it has been possible to define and implement extremely advanced simulation techniques In general all improvements and expansions in air pollution dispersion modelling stem from the three basic theories (statistical, similarity and gradient transfer) or the Gaussian

approach (Chapter 2) In spite of so much progress, none of the existing modelling/simulation techniques yield reasonable predictions Since air pollutant dispersion models are the only tool for inferring a quantitative regulatory applications, continuous efforts are made for improving the present simulation capabilities which would allow the models to reach the expected level of performance These efforts aim at (1) the development and application of more complex and sophisticated methodologies, generally requiring more advanced meteorological information, and (2) the improvement of the simulation capabilities of relatively simple current techniques, mainly using the available meteorological information Simulation techniques adopted in the current package employ simulation capabilities of relatively simple recently developed techniques (Nema and Tare, 1989; Nema, 1987, Zannetti, 1986) The methodology appears to simulate complex dispersion conditions in both transport and calmwind situation while maintaining the simplicity of the basic Gaussian approach

Selection of programming language and software environment is a relatively easy task since not many choices are available TURBO PASCAL version 4 0 which supports good graphic facilities is utilized in the present package The advantage is that the programmes can be executed from outside the TURBO package and hence the provisions of MS DOS environment are fully utilized

4 STRUCTURE OF INDISPOL

4 1 General Package Programme Logic

The present package has been developed keeping in view the general nature of the package and expected usage by the end user Since the ultimate objective of the package is to provide the user a facility to simulate pollutant concentration profile under varying dispersion conditions using different simulation techniques and to produce output in digital and/or graphical form depending upon one's judgement/requirement, the algorithm has been developed as a multi-branched selection process which logically ends into the execution of the programme for selected option and display/storage of output It is also assumed that the user may have little or no programming knowledge Thus the package has been written such that the user does not have to call upon special programming skills or knowledge, except for knowing elementary concepts about operation of a PC and giving execution commands

The package programmes have been developed on an IBM PC compatible The programme is written in PASCAL The graphic visuals and interaction are accomplished by TURBO PASCAL - version 4 0 The editing facilities for input/output is provided by giving access to WORDSTAR 2000 from within the package at required places and re-entering into the package at the same place The current version of the package and its subsequent modifications are expected to run on IBM PC-XT or compatible with or without a colour monitor The package itself is protected from unauthorised use by a password code without which it can not be opened by the user

The algorithm of the package programme can be best represented by a macro flow chart presented in Fig 4 1 The logic can be broadly divided into (1) package access code, cover page and general utilities, (2) menu generation and problem identification (selection of model/simulation technique and output form) from them, (3) acceptance of input, display and editing of

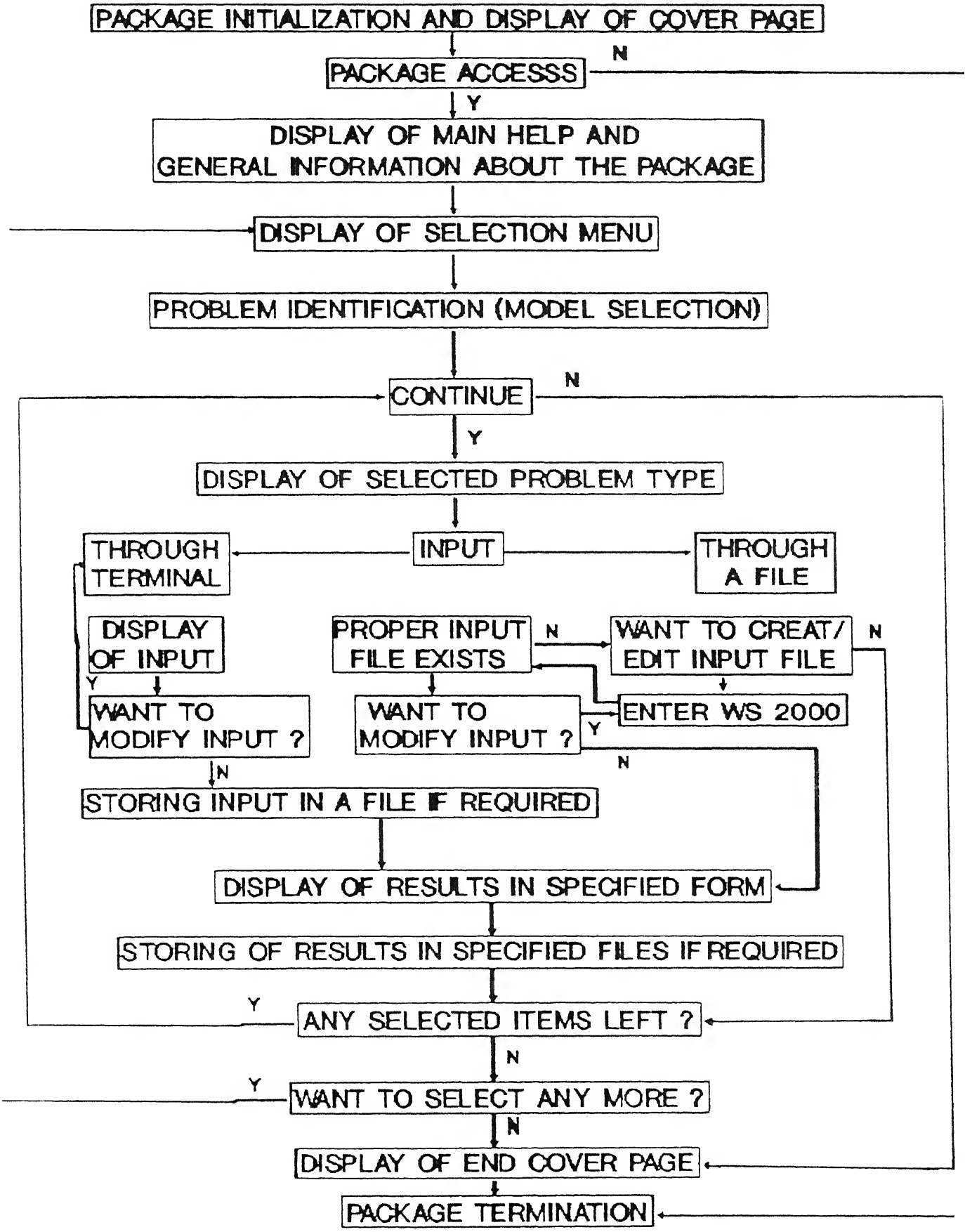


Fig 41 Macro flow chart of package programme

input, and checking/storing of input, (4) execution of appropriate programme, (5)display of digital/graphical output, (6) en-queueing the output, and (7) saving of output on a file in the user area for future reference and retrieval

For speedy processing and to avoid any memory problems, the entire package programme is made up of different programmes which are executed with proper controls through a batch file in MS DOS environment (MS DOS version 3 3 or later)

4.2 Menus and Problem Identification

All selectable items of a menu are written in individual windows and the menu identification itself occupies a separate window The selection of a menu item is effected through an arrow (→ ↑ ← ↓) key on the keyboard The forward movement of the user through the list of menus is affected by successive selection of the desired menu item, the backword movement of the user is caused by pressing F2 or through selection of STAY option The package is designed to provide the user "on-line-help" to guide him through the package and a guide option to assist in problem identification The help is obtained by selecting HELP or pressing F1 while GUIDE is a menu selectable item The other options provided for easy movement in the package include NEXT (F3) option to continue with current selection, QUIT (F4) option to quit or exit from the package and PRINT (F5) option to print screen display

4 3 Selection Identification and its Implementation

Each terminal selection is identified by a unique identification number and it's referred to by that number throughout the package programme execution The various terminal selections of the package and their identification numbers are given in Table 4 1 Each identified problem type is programmed according to the concepts and procedures described in Chapters 5 and 6

Table 4.1. Identification Numbers and Dummy Files Associated with Various Terminal Selections.

Selection	Identification Number	Corresponding Dummy File
UNIS-DIGITAL	1100	ALG.11
-GRAPHICAL	1200	ALG.12
MULTYS-RECPCONC	2100	ALG.21
-CONTOUR	2200	ALG.22
PUFFS-DIGITAL	3000	ALG.30
-GRAPHICAL	3100	ALG.31
SEGMNT-DIGITAL	4000	ALG.40
-GRAPHICAL	4100	ALG.41
PUFSEG-DIGITAL	5000	ALG.50
-GRAPHICAL	5100	ALG.51
GUIDE-UNIS	6100	GUIDE.61
-MULTYS	6200	GUIDE.62
-PUFFS	6300	GUIDE.63
-SEGMNT	6400	GUIDE.64
-PUFSEG	6500	GUIDE.65
EDITOR	7000	OPDEM
DISPLAY-UNIS	7100	DIS.71
-MULTYS	7200	DIS.72
-PUFFS	7300	DIS.73
-SEGMNT	7400	DIS.74
-PUFSEG	7500	DIS.75

4.4 Simulation Techniques

In all five simulation techniques identified as "UNIS", "MULTYS", "PUFFS", "SEGMNT" AND "PUGSEG" are employed UNIS uses simple Gaussian model to simulate pollutant dispersal from single steady and continuous emission source which may be a ground or elevated point source in a stationary and homogeneous atmosphere MULTYS uses same model as UNIS with the modification that the effect due to multiple sources is considered by linear superposition of the effect due to several single independent sources Further details are presented in Chapter 4

PUFFS, SEGMNT and PUFSEG are based on extended Gaussian approach and are used to simulate pollutant dispersal from single unsteady ground or elevated point source in non-stationary and inhomogeneous atmosphere in predominantly calmwind, transport and lightwind conditions respectively Mathematical details and algorithms for these simulation techniques are presented in Chapter 6

4.5 The Package Programmes

The package comprises of several programmes which in turn consist of several procedures and functions Following is a list of programmes and their functions in brief

1 INTRODUC EXE Initializes package by displaying first cover page and deletes several dummy files (which are used as control files and created during the execution of the package), if exist

2 PERMIT EXE· Displays passcode option and allows access to the package only if correct passcode is given Else makes the file DUMY which leads to termination of the package

3 INFO EXE Gives general utilities and information about the package

4 MAINMENU.EXE Displays menu of various levels, allows selection of a particular option through forward or backword movement, gives help messages to have desired movement in the package and guides in making appropriate selections Exit from this programme creates dummy files HLPDUMY, DUMY and MENU OUT depending upon the selections made

5 RUNN EXE Reads various identification numbers from MENU OUT and creates corresponding dummy files (Table 4 1)

6 DOL1 EXE Deletes DMLV1 and DMLV11, if exist Checks the existence of the proper input file if the option selected is UNIS-DIGITAL and the input is through a file (INP1), creates dummy file DMLV1, if proper input file does not exist and is to be created/edited, else creates another dummy file DMLV11 leading to ignoring the current selection

7 DOL2 EXE· Same as DOL1 EXE but for selection UNIS-GRAPHICAL Files DMLV1 and DMLV11 are replaced by DMLV2 and DMLV12 respectively

8 DOL3 EXE· Same as DOL1 EXE but for selection MULTYS-RECPCONC Files INP1, DMLV1 and DMLV11 are replaced by INP2, DMLV3 and DMLV13 respectively

9 DOL4 EXE· Same as DOL1 EXE but for selection PUFFS-DIGITAL Files INP1, DMLV1 and DMLV11 are replaced by INP3, DMLV4 and DMLV14 respectively

10 DOL5 EXE Same as DOL1 EXE but for selection SEGMNT-DIGITAL Files INP1, DMLV1 and DMLV11 are replaced by INP3, DMLV5 and DMLV15 respectively

11 DOL6 EXE· Same as DOL1 EXE but for selection PUFSEG-DIGITAL Files INP1, DMLV1 and DMLV11 are replaced by INP3, DMLV6 and DMLV16 respectively

12 DOLL EXE When the EDITOR option is selected, through this programme a dummy file DUM1 is created, existance of which sends the control to the main menu after editing facilities

13 EDIT EXE· Displays the EDIT-GUIDE and allows excess to WORDSTAR-2000 for editing

14 CALTABLE EXE· Allows display of stability classification (TABLE 1) and coefficients employed for computing dispersion standard deviations using power laws (Table 2)

15 GUID1 EXE· Displays guide lines for selection UNIS

16 GUID2 EXE Displays guide lines for selection MULTYS

17 GUID3 EXE Displays guide lines for selection PUFFS

18 GUID4 EXE· Displays guide lines for selection SEGMNT

19 GUID5 EXE· Displays guide lines for selection PUFSEG

20 CHECK EXE· Deletes MENU-OUT and DUM, if exists Allows more selection if required by creating dummy file DUM

21 LAST EXE It deletes all dummy files created during the execution of the package and displays end cover pages

4.6. Auxillary and Other Files

The execution of the package involves the use of auxillary files GLBUNIT, UNITDGTL, UNITGRF, UNITMUL, UNITPUF, UNITSEG and UNITPFSG along with software MS DOS (version 3 3 or later), TURBO PASCAL (version 4 0) and WORDSTAR 2000 Each of the programmes mentioned in section 4 5 uses some or all of the auxillary files The auxillary file GLBUNIT contains a number of procedures and functions to (1) give various types of audio signals, (2) display different messages, (3) permit accepting real value only, (4) permit accepting interger value only, (5) accept response YES or NO, (6) read and display stability classification and dispersion standard deviation coefficients tables and (7) check if the desired files exist in the user area/disk Function and description of auxillary files UNITDGTL, UNITGRF, and UNITMUL are presented in Chapter 5 while the same for UNITPUF, UNITSEG and UNITPFSG are given in Chapter 6

In addition to auxillary files there are several input and output files which are required/created during the execution of the package These files can be classified in two categories, (1) dummy files and (2) real files Dummy files are created to transfer proper control from one programme to the other and are deleted automatically upon the termination of the package or in between Real files can be accessed by the user and can be read from outside the package Names of real files can be supplied by the user

5 UNIS AND MULTYS

POLLUTANT DISPERSION IN STATIONARY AND HOMOGENEOUS ATMOSPHERE

5.1 Scope

This chapter presents algorithms employed in developing computer programmes for the simulation of concentration computation of gaseous pollutants released from steady (single/multiple, ground/elevated) point source(s) in stationary and homogeneous atmosphere using the basic Gaussian approach A brief description of the concepts and mathematics involved is given to assist in understanding the algorithms

5.2 Gaussian Formulation

The Gaussian formulation for atmospheric dispersion attempts to simulate the gross behavior of plumes emitted from ground/elevated sources For localised point sources such as a stack, the general appearance of the plume might be represented by the schematic shown in Fig 5 1 Although the plume originates at a stack height H_s, it rises an additional height ΔH (Plume rise), owing to the buoyancy and momentum of the gases leaving the stack Consequently, for practical purposes the plume appears to be originating from a point source at an equivalent stack height H (effective stack height) = $H_s + \Delta H$

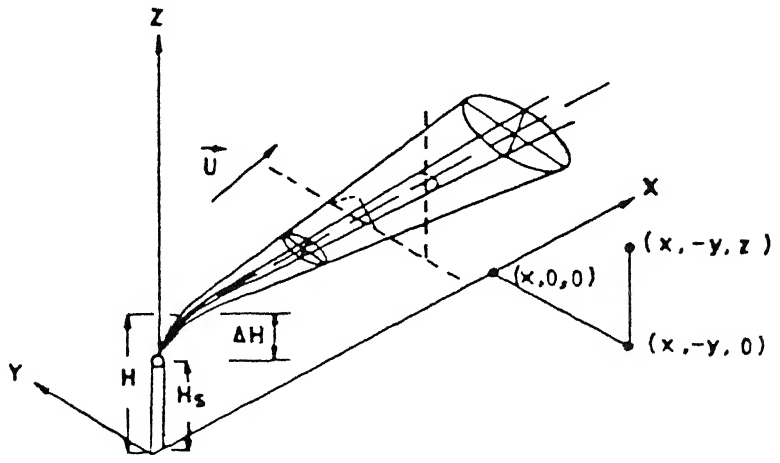


Fig. 5.1 Wind oriented coordinate system indicating an elevated point source located at (0,0,

The formulation is based on the approximation that the concentration distribution downwind of a point source in the atmospheric boundary layer is Gaussian but with unequal dispersion parameters in the horizontal (crosswind) and vertical directions For development of mathematical model a wind oriented coordinate system is employed in which the x axis coincides with the prevailing wind direction (Fig 5 1) The geometric factor that represents the ratio of the concentration at an arbitrary off-axis location (x,y,z) to the concentration at the centreline of the plume is therefore given by

$$F(x,y,z) = \exp\left\{-\frac{y^2}{2\sigma_y^2} - \frac{z^2}{2\sigma_z^2}\right\} \qquad (5\,1)$$

Gaussian distribution is used in the atmospheric boundary layer even though the turbulence there is not isotropic (e g, $\bar{u}'^2 \neq \bar{w}'^2$) or homogeneous (e g, $\bar{w}'^2$ is a function of z) Unequal lateral and vertical dispersion coefficients are used to compensate, at least in part for these departures

The geometric factor F(x,y,z) has the value of unity along the plume axis where y = z = 0 and therefore represents the quantity which should be multiplied by the axial concentration c(x,0,0) to yield the concentration at any arbitrary position

$$c(x,y,z) = c(x,0,0)\ F(x,y,z) \qquad (5\,2)$$

The axial concentration c(x,0,0) is determined by considering species conservation i e source strength Q is equal to its flow rate through any plane normal to the x axis This requires the assumption of steady and continuous emisson The species flow rate through an elemental area dA normal to u is cudA and therefore the conservation of mass requires that the flow through any downwind x plane is equal to the source strength

$$Q = u\ c(x,0,0) \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} F(x,y,z)\ dy\ dz \qquad (5\,3)$$

The integral is readily evaluated as

$$\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} F(x,y,z)\ dy\ dz = 2\ \pi\ \sigma_y(x)\ \sigma_z(x) \qquad (5\,4)$$

Thus the centreline concentration can be given by

$$c(x,0,0) = \frac{Q}{2\pi\, u\, \sigma_y \sigma_z} \tag{55}$$

The spatial variation of concentration downwind of the source can be obtained by inserting Eqs 51 and 55 into Eq 52

$$c(x,y,z) = \frac{Q}{2\pi\, u\, \sigma_y \sigma_z} \exp\left\{-\frac{y^2}{2\sigma_y^2} - \frac{z^2}{2\sigma_z^2}\right\} \tag{56}$$

Eq 56 gives the basic Gaussian plume formula which can be used to compute downwind concentration from an isolated point source located at the origin (0,0,0) in a medium of infinite extent if the values of dispersion coefficients are properly chosen The concentration for an elevated point source can be found by relocating the source at the point (0,0,H) and by a translation of the coordinate system where z is replaced by z-H

$$c(x,y,z) = \frac{Q}{2\pi\, u\, \sigma_y \sigma_z} \exp\left\{-\frac{y^2}{2\sigma_y^2} - \frac{(z-H)^2}{2\sigma_z^2}\right\} \tag{57}$$

For a ground level source, the vertical spread of the plume is restricted in 0 to $+\infty$ region and hence the downwind concentration expression takes the form

$$c(x,y,z) = \frac{Q}{\pi\, u\, \sigma_y \sigma_z} \exp\left\{-\frac{y^2}{2\sigma_y^2} - \frac{z^2}{2\sigma_z^2}\right\} \tag{58}$$

Eq 57 for an elevated source is often expanded with a reflection term if the surface is not a 100% sink for pollutant The downwind concentration with reflection is determined mathematically by linear superposition of two Gaussian type concentration curves, one centred at H (real) and the other at -H (imaginary) The strength of imaginary source is taken as some fraction (P_{ref}, a parameter related to the characteristics of the ground surface and pollutant) of the strength of real source Eq 57 with reflection term takes the form

$$c(x,y,z) = \frac{Q}{2\pi\, u\, \sigma_y \sigma_z}\left[\exp\left\{-\frac{y^2}{2\sigma_y^2} - \frac{(z-H)^2}{2\sigma_z^2}\right\} + P_{ref}\exp\left\{-\frac{y^2}{2\sigma_y^2} - \frac{(z+H)^2}{2\sigma_z^2}\right\}\right] \quad (5.9)$$

5.3 Application of Gaussian Formulae

Application of the aforementioned Gaussian formulae requires information about pollutant emission rate Q, effective stack height H, wind velocity u, dispersion parameters σ_y and σ_z, and reflection parameter P_{ref} While emission rate can be estimated/measured fairly accurately, estimations/measurements of H, u, σ_y, σ_z and P_{ref} have to be based on some assumptions and idealizations The following sections describe the technique/procedure adopted for reasonable estimates of these parameters

Effective stack height Effective height H of the virtual origin of plume is obtained by adding a term ΔH, the plume rise, to the actual stack height H_s There are numerous methods for calculating ΔH, and these are discussed at some length by Stern (1968) Basically, three sets of parameters control the rise of a gaseous plume injected into the atmosphere from a stack These are stack characteristics, meteorological conditions, and the physical and chemical nature of the effluent A large number of analytical expressions have been proposed to relate these factors to plume rise predictions Carson and Moses (1969) compared 711 observed plume rise values with calculated values given by eleven different equations Their conclusion was that the following three equations for unstable, neutral and stable atmosphere predict reasonably accurate ΔH values

$$\Delta H = 3.47\ \frac{V_s D_s}{u_s} + 5.15\ \frac{(Q_h)^{0.5}}{u_s} \quad \text{(unstable)} \quad (5.10)$$

$$\Delta H = 0.35\ \frac{V_s D_s}{u_s} + 2.64\ \frac{(Q_h)^{0.5}}{u_s} \quad \text{(neutral)} \quad (5.11)$$

$$\Delta H = -1.04\ \frac{V_s D_s}{u_s} + 2.24\ \frac{(Q_h)^{0.5}}{u_s} \quad \text{(stable)} \quad (5.12)$$

Here V_s is the stack gas exit velocity in m/s, D_s is the stack

exit diameter in m, u_s in m/s and Q_h is the the heat emission rate in KJ/s

Wind velocity The wind velocity varies with altitude (z) and the typical variation of u with z can be obtained by following equation which includes a factor to adjust for various stability conditions in the atmosphere

$$\frac{u_2}{u_1} = \left\{\frac{z_2}{z_1}\right\}^{\frac{R}{2-R}} \qquad (5\ 13)$$

Here u_1 and u_2 are the wind velocities at heights z_1 and z_2 respectively, and R is the stability parameter which is related to stability condition of the atmosphere (Wark and Warner, 1981) The appropriate value of u to use in the dispersion equations is the mean value taken through the plume (Turner, 1969) In most cases it would be impossible to determine the mean, since sufficient atmospheric data would not be available In lieu of this, the average wind velocity at the top of the stack is commonly used Since in most cases not even this value is known, the measured meteorological value at 10m is used in conjunction with Eq 5 13 to estimate the wind velocity at the plume height

Dispersion standard deviations· As might be anticipated from the physical description of the diffusion problem, the horizontal and vertical dispersion standard deviations, σ_y and σ_z, are a function of the donwind position x as well as the atmospheric stability conditions Many experimental measurements in the atmosphere have led to an evaluation and correlation of σ_y and σ_z values There are several sets of charts for these two parameters, and the range of stability conditions covered in the different sets do not normally coincide

Dispersion standard deviations are determined by the mixing or dispersive power of the turbulent flow within the atmospheric boundary layer For this purpose the state of the boundary layer is characterized by Pasquill (1974), as being in one of the nine (A, A-B, B, B-C, C, C-D, D, E, F) classes which

are reported in several text books (e.g. Wark and Warner, 1981; Dobbins, 1979). Determinants of the dispersion classes are wind speed and the state of incoming or outgoing solar radiation which affect the lapse rate, presence or absence of convective activity, and the dynamics of the mixed layer.

For computational purposes it is desirable to have the two standard deviations expressed in mathematical form. Due to logarithmic nature of the σ variations with downwind distance x, a reasonable curve fit is obtained by power law expressions. Thus algebraic representation of σ_y and σ_z is frequently expressed in terms of the expressions of the type

$$\sigma_y = a\ x^p \text{ and } \sigma_z = b\ x^q \quad (x, \sigma_y \text{ and } \sigma_z \text{ in m; Tadmor and Gur, 1969}) \qquad (5.14)$$

or

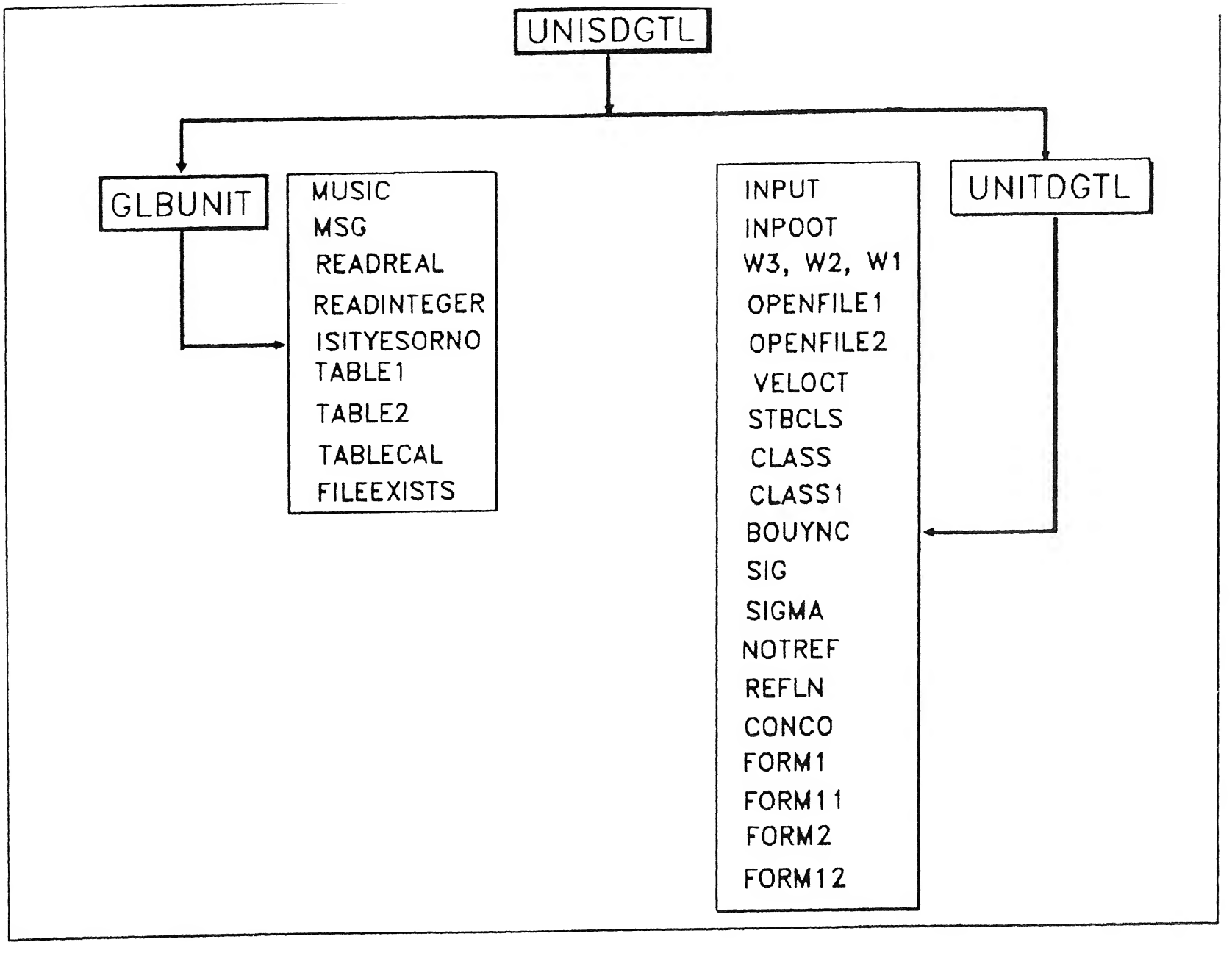
$$\sigma_y = a\ x^b \text{ and } \sigma_z = c\ x^d + f \quad (x \text{ in km}, \sigma_y \text{ and } \sigma_z \text{ in m; Martin, 1976}) \qquad (5.15)$$

where a, b, c, d, f, p and q are empirical constants which depend on the stability class and wind velocity (Wark and Warner, 1981; Dobbins, 1979).

Reflection parameter: As mentioned earlier, reflection parameter P_{ref} is influenced by the characteristics of the surface and the pollutant. No general guidelines are available for selecting the value of P_{ref} and has to be based on intuition and experience.

5.4 Option UNIS

This option is for predicting the downwind, crosswind and vertical cocentration profiles due to steady and continuous emissions from a single point source under stationary and homogeneous atmospheric conditions. It has two sub options DIGITAL and GRAPHICAL to give output in digital and graphical form respectively. Correspondingly there are two separate programmes UNISDGTL and UNISGRF. UNISDGTL uses units GLBUNIT (Ref. Sec.4.6) and UNITDGTL (Fig. 5.2) while UNISGRF uses GLBUNIT and UNITGRF



Fg 5.2 Programme tree for UNISDGTL

(Fig 5 3) Units GLBUNIT, UNITDGTL and UNITGRF consist of several subprogrammes Fig 5 4 presents the schematics of the logic adopted in UNISDGTL and UNISGRF which constitutes option "UNITS" Details are available elsewhere (Nema and Tare 1988; Nema, 1987) Following is the brief description/function of various subprogrammes used in units UNITDGTL and UNITGRF

(1) INPUT, INPOOT· All data are read through these subprogrammes and can be given through an input file or terminal in an interactive mode and can be stored in a file depending upon users choice The input data consists of the following

a Source - emission rate, heat content of the gaseous stream, exit velocity, physical stack height and stack diameter

b Meteorology - wind velocity measured at a specified altitude, environmental lapse rate, data about day (1) or night (2), solar radiation i e strong (1), moderate (2) or slight (3) and cloud coverage i e clear (1) or overcast sky (2)

c Domain - specifies minimum and maximum distances (alongwith the interval) in which the pollutant concentration profiles are desired

2 W3, W2, W1 These subprogramme s make different windows on the screen for desired pattern of screen display

3 OPENFILE1, OPENFILE2· OPENFILE1 assigns and resets the input file to INP1 while OPENFILE2 checks whether the user wants to store the output in a file or not It can store the output in a user specified file

4 VELOCT· This subprogramme computes wind velocity at any altitude according to a power law by selecting appropriate stability parameter related to the stability condition of the atmosphere

5 STBCLS This subprogramme selects appropriate stability index (1 to 6 for stability classes A to F respectively) corresponding to the meteorological data and wind velocity at 10m height

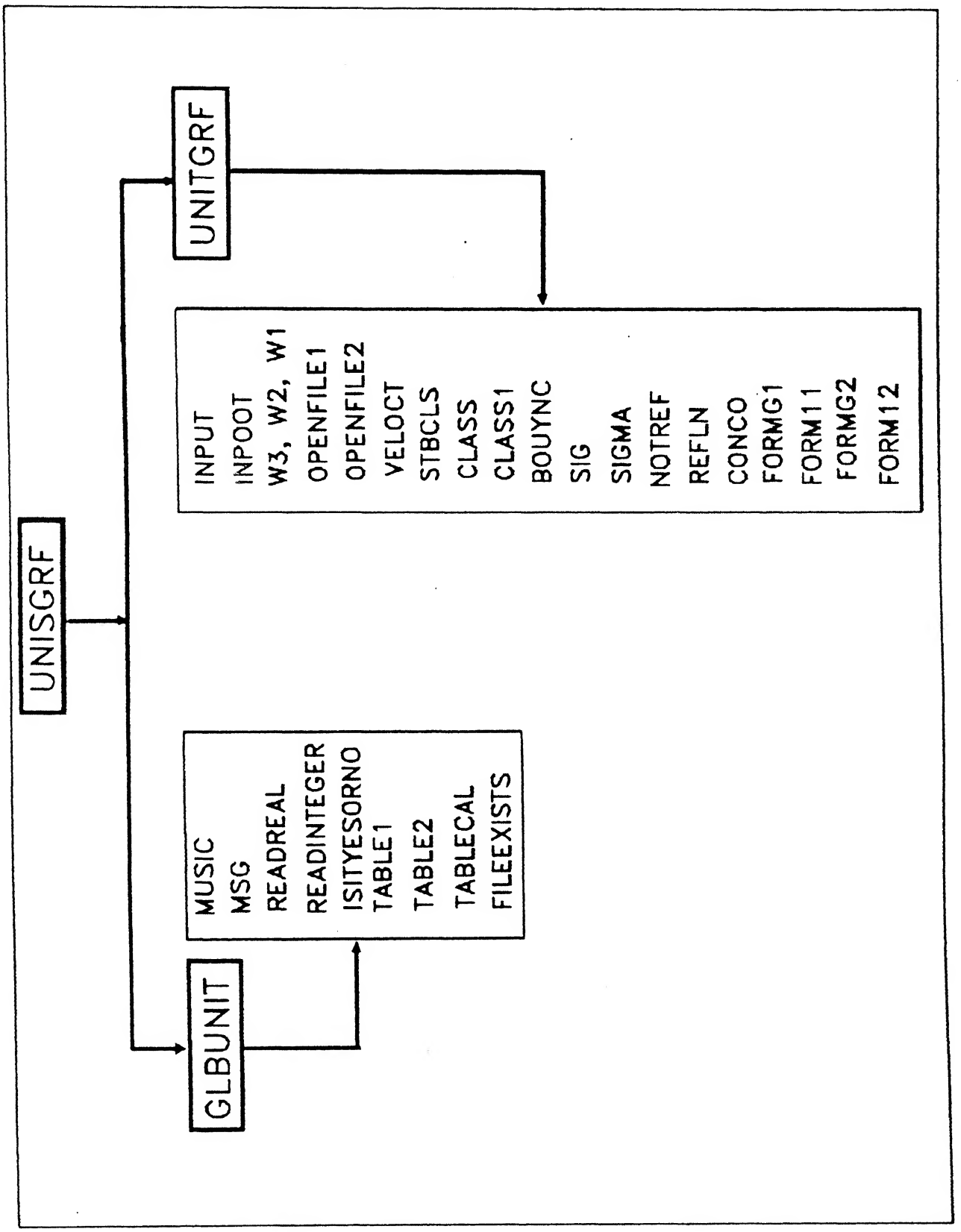


Fig. 5.3 Programme tree for UNISGRF

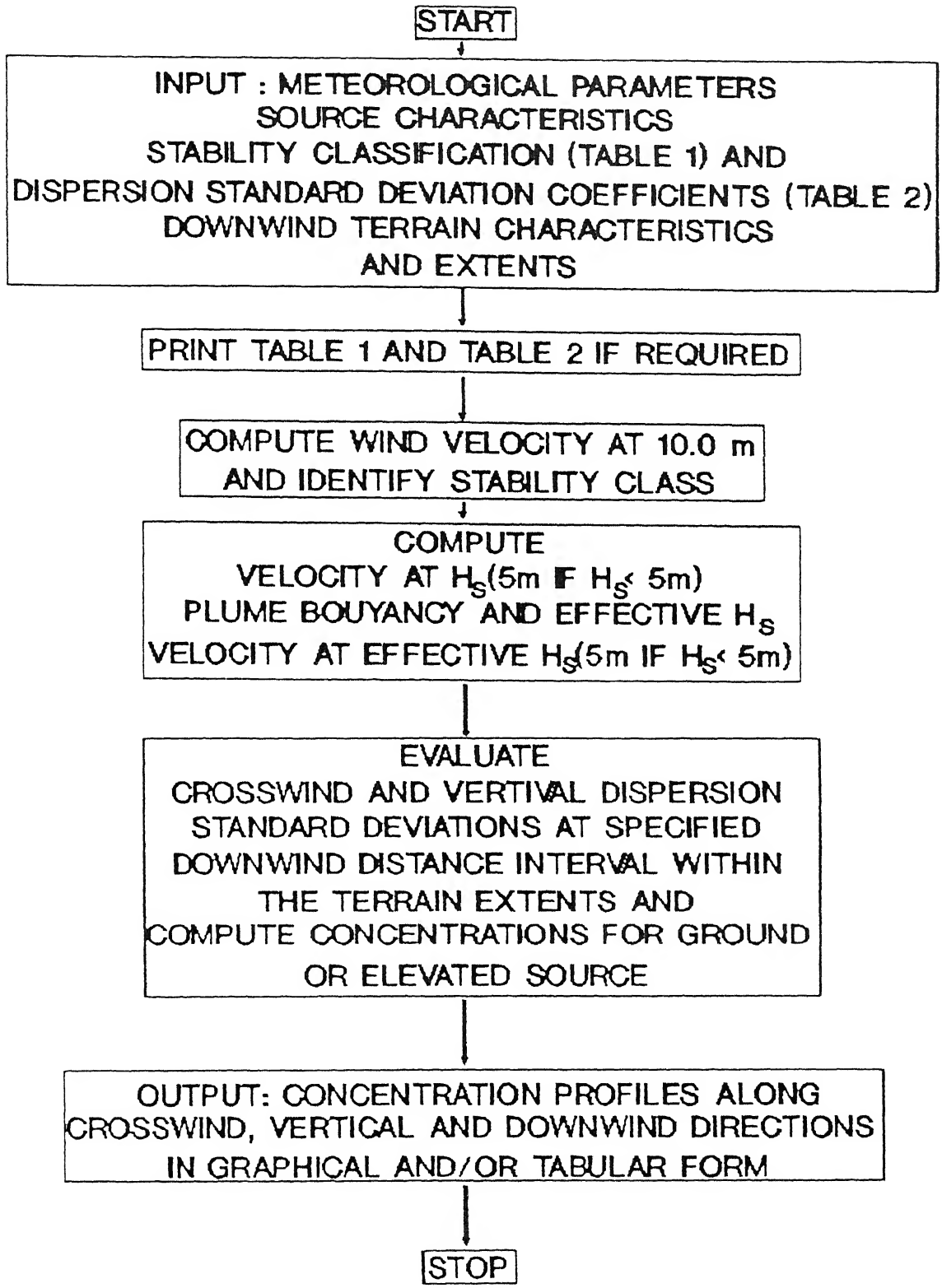


Fig. 5.4 Schematic representation of the logic adopte in developing option "UNIS"

6 CLASS, CLASS1: Subprogramme CLASS decodes the stability class and the subprogramme CLASS1 writes the same in a output file

7 SIG, SIGMA The various empirical constants involved in power law for computing dispersion standard dviations are assigned in SIGMA while in SIG, σ_y and σ_z are computed

8 BOUYNC: This subprogramme computes the plume rise and effective stack height Appropriate expression for plume rise is selected depending upon the stability class Stability classes A to C are considered as unstable, D is considered as neutral, and E and F are considered as stable

9 NOTREF, REFLN, CONC Subprogrammes NOTREF and REFLN compute the crosswind and vertical concentration profiles in the specified domain at equal interval for a pollutant released from an elevated point source Concentration is computed with REFLN when the plume impinges on the surface The maximum crosswind distance is selected corresponding to 10% of the plume centre line concentration on either side subject to its not being greater than 20 km Significant vertical distance is taken as the distance between plume centreline and the ground level, on either side of the plume centreline at a particular downwind distance

The subprogramme CONCO is similar to NOTREF except (1) wind velocity is taken at 5m height, (2) vertical concentration profile is computed from surface level to a distance where 10% of the surface level concentration is obtained subject to its not being greater than 20 km To avoid floating underflow errors and save on computational efforts, the concentration is set to zero if the exponent is less than -25 in all the subprogrammes.

FORM1, FORM2, FORM11, FORM12 These subprogrammes are included to write crosswind and vertical concentration profiles on terminal and output file in digital form

FORMG1, FORMG2 These subprogrammes display on the screen crosswind and vertical concentration profiles in graphical form

5 5 Option MULTYS

This option is for predicting pollutant concentration in a stationary and homogeneous atmosphere using Gaussian approach (Sections 5 2 and 5 3) for a pollutant continuously released from multiple point sources (ground level or elevated) at constant emission rates It has two sub options RECPCONC and CONTOUR to give pollutant concentrations at selected locations in digital form and isoconcentration lines in the selected domain respectively However, the second option is not completely developed The first option is implemented through a programme named RECPCONC and uses units GLBUNIT and UNITMUL which in turn consist of several subprogrammes (Fig 5 5) These subprogrammes are similar to those used in UNISDGTL/UNISGRF except for some minor changes as follows

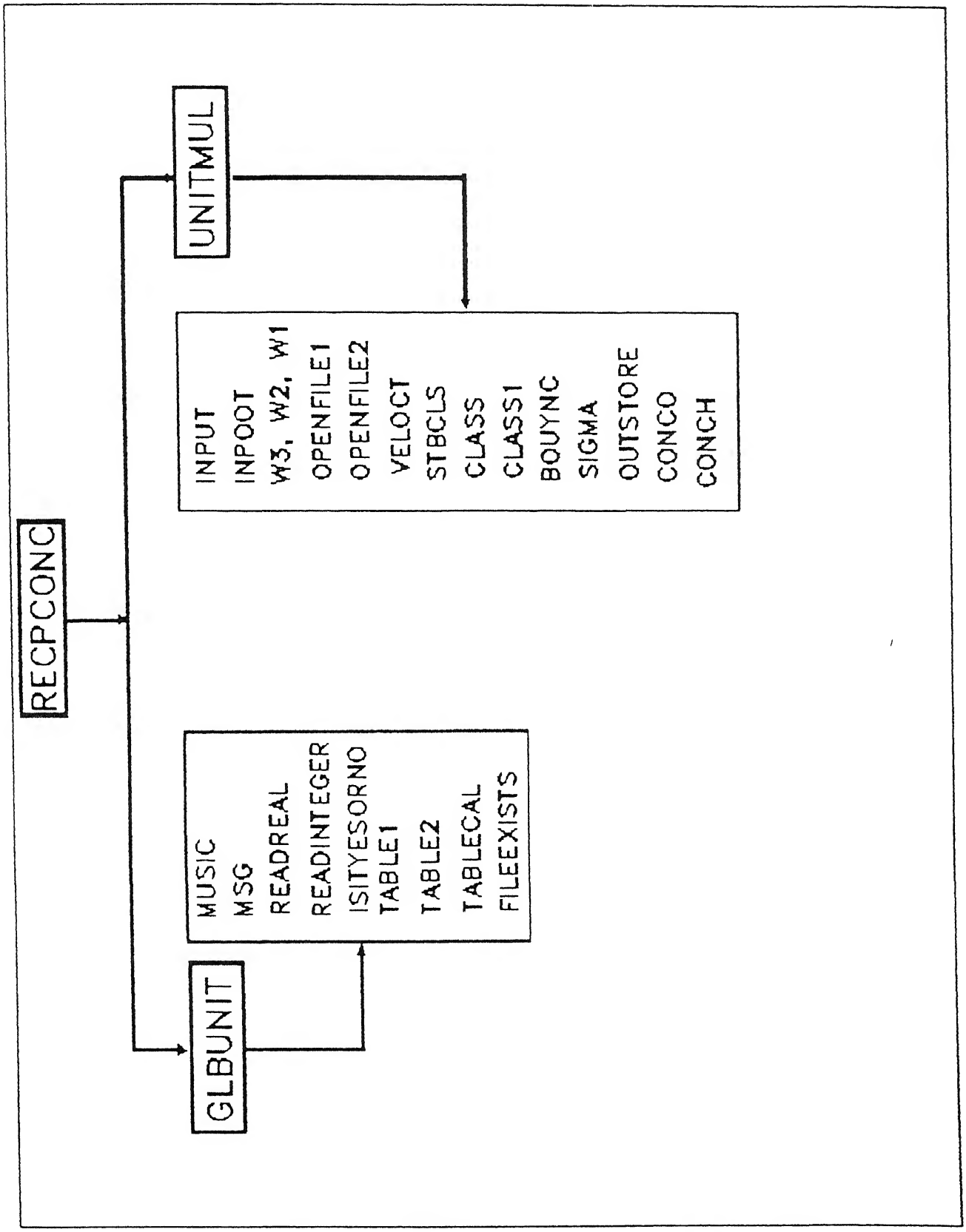
(1) INPUT, INPOOT - Source characteristics are to be given alongwith location for more than one sources, and receptor number and locations are to be specified instead of domain

(2) CONCH - This computes concentration due to elevated source considering both reflection and no reflection

(3) SIGMA - Subprogrammes SIG and SIGMA (Fig 5 2) are combined into this subprogramme

(4) Concentration contribution from a source is computed only if the receptor is located downwind of a particular source The aggregate concentration at a receptor is computed by linear superposition, neglecting the interference due to multiple sources

Schematics of the logic adopted in developing the programme RECPCONC is presented in Fig 5 6


RECPCONC
UNITMUL
INPUT
INPOOT
W3, W2, W1
OPENFILE1
OPENFILE2
VELOCT
STBCLS
CLASS
CLASS1
BOUYNC
SIGMA
OUTSTORE
CONCO
CONCH
GLBUNIT
MUSIC
MSG
READREAL
READINTEGER
ISITYESORNO
TABLE1
TABLE2
TABLECAL
FILEEXISTS

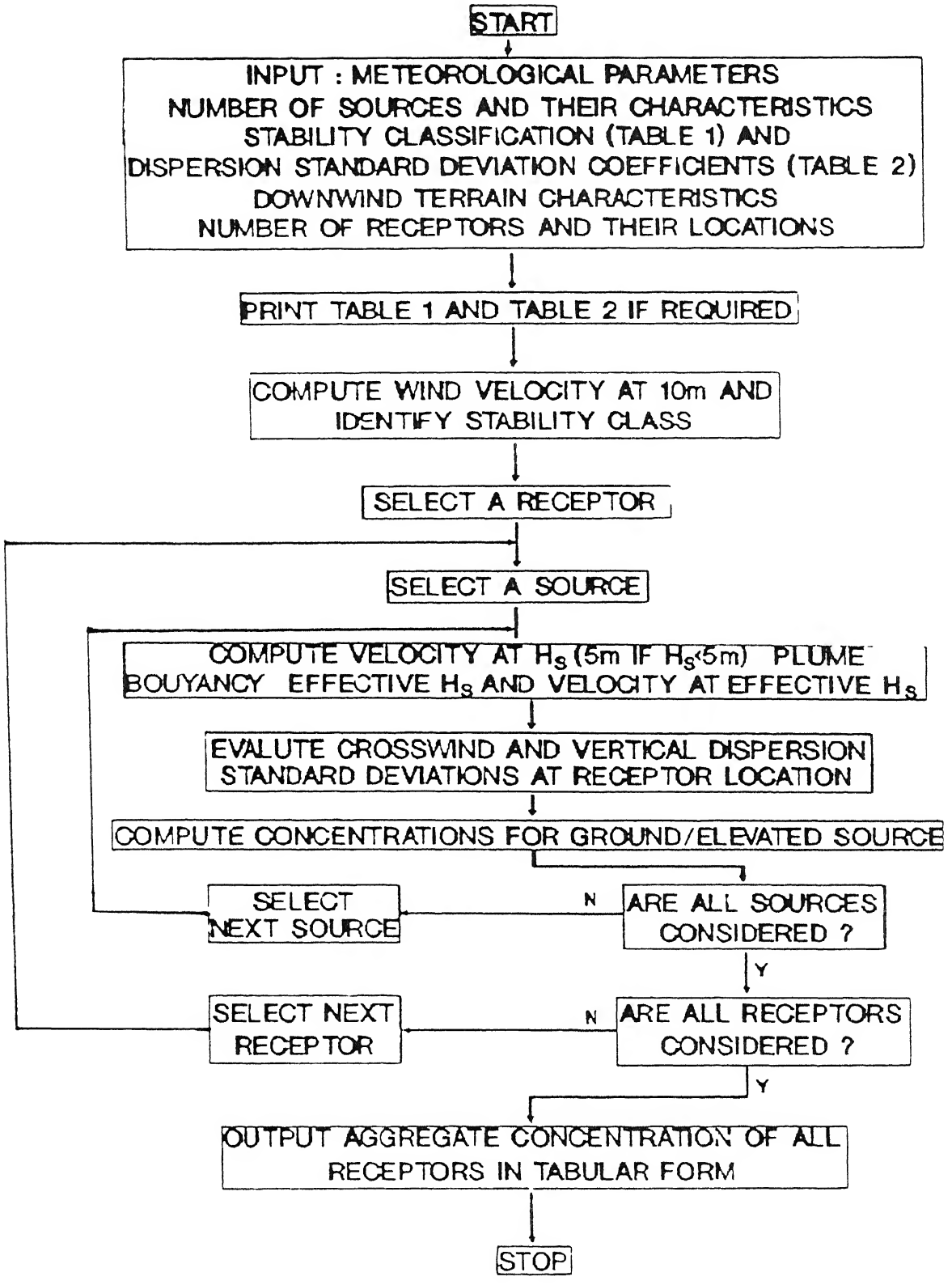


Fig 5.6 Schematic representation of the logic adopted in programme "RECPCONC"

6 PUFFS, SEGMNT AND PUFSEG POLLUTANT DISPERSION IN NON-STATIONARY AND INHOMOGENEOUS ATMOSPHERE

6.1 Scope

The ultimate goal of the dispersion modelling is to provide a methodology to predict pollutant dispersal in a real life situation This involves complete analysis of dispersion phenomena in non-stationary and inhomogeneous atmosphere for a pollutant released from a non-steady source Certainly, a problem of this nature cannot be analyzed without simplified assumptions and idealizations In this study atmospheric dispersion phenomena for aforementioned conditions is simulated using extended Gaussian approach This chapter briefly describes the concepts and mathematics involved in developing computer programs for the three formulations namely PUFF (for essentially calmwind conditions), SEGMENT (for transport conditions) and mixed PUFF-SEGMENT (for lightwind conditions)

6 2 PUFF Formulation

The basic Gaussian approach (Eqs 5 7 and 5 9) described in previous chapter gives a plume formula whose validity requires the main assumptions of (i) spatial homogeneity, (ii) stationary conditions and (iii) steady continuous emissions Further, these equations cannot be used directly in calmwind conditions where $|u| = 0$ However, simplicity of the Gaussian approach, its relatively easy use with clearly measureable meteorological parameters and especially the elevation of this method to the quantitative decision-controlling level have stimulated research aimed at removing the limitations of the Gaussian theory to treat the complex situations of the real world In particular, the PUFF approach (Lamb and Neiburger, 1971) has been successfully applied to pseudo steady-state conditions Several studies (Zannetti, 1981, Sheih, 1978; Ludwig, *et al*, 1977) have discussed in detail the PUFF modelling approach, improving its application features

The most obvious way of treating non-stationary conditions in emissions/meteorology, is to describe the point source emission into the atmosphere by a series of "instantaneous" puffs whose characteristics are updated at each dispersion interval Δt Meteorological three dimensional fields (wind and turbulent status) and emission parameters are allowed to change at each meteorological time step (Δ_{met}) Dynamics of each puff consist of (1) generation at the source, (2) plume rise; (3) transport by advective wind; (4) diffusion by atmospheric turbulence, (5) ground deposition, dry and wet, and (6) chemical transformation Each puff is characterized by the following time varying parameters evaluated at its central point

(CPX, CPY, CPZ) coordinates of the centre point of puff

h_p elevation of centre point above ground (in flat terrain h_p = CPZ)

M pollutant mass in Puff

σ_Y, σ_Z standard deviations of the Gaussian concentration distribution

Generation of plume At each time interval Δt, a new puff is added to the puff 'chain' from the source The parameters defining each new puff have the following initial values The central point is set at the source's exit point plus the vertical plume rise ΔH, $M = Q(t)\,\Delta t$, where $Q(t)$ is the current emission rate, and σ_y, σ_z represent initial σ's of the plume ($\sigma_y = 0.369\,D_s$ and $\sigma_z = \Delta H/3.16$, Zannetti, 1986)

Advection At each time interval Δt, central point of each existing puff is advected according to the current wind vector $\vec{U} = (u,v,w)$ at puff's location as follows

$$(CPX,CPY,CPZ)^{(new)} = (CPX,CPY,CPZ)^{(old)} + \vec{U}\,\Delta t \qquad (6.1)$$

Diffusion During each Δt the puff's σ's are basically computed using power law expressions (Eqs 5.14 or 5.15) in which puff's direct distance from the source is substituted for x

However, virtual distance (transport conditions)/virtual age (calmwind conditions) concept is used whenever meteorology (i e stability class) is different at puff's new and old centre point either due to non-stationary or non-homogeneous condition of the atmosphere [Ludwig *et al*, 1977, Zannetti, 1981]

Virtual distance concept for σ computation: 1 Current σ function (corresponding to new stability class) is equated to $\sigma^{(old)}$ to calculate appropriate virtual distance (d_{V_H} for σ_y and d_{V_z} for σ_z)

$$d_{V_H} = \left\{\frac{\sigma_y^{(old)}}{a}\right\}^{1/p} \quad \text{and} \quad d_{V_z} = \left\{\frac{\sigma_z^{(old)}}{b}\right\}^{1/q} \quad \text{in SIGMA1} \qquad (6.2)$$

$$d_{V_H} = \left\{\frac{\sigma_y^{(old)}}{a}\right\}^{1/b} \quad \text{and} \quad d_{V_z} = \left\{\frac{\sigma_z^{(old)} - f}{c}\right\}^{1/d} \quad \text{in SIGMA2} \qquad (6.3)$$

2 New values of σ's are obtained by substituting (dv + U Δt) for x in Eqs 5.14 or 5.15

Virtual age concept for σ computation: 1 In calmwind conditions (i e U < U_{min}, U is taken as U_{min}) σ's are considered as functions of time (more exactly, the age) in power law expressions (Eq 5.14 or 5.15) instead of downwind distance. Simlar to virtual distances, virtual ages (t_{V_H} for σ_y and t_{V_z} for σ_z) are computed as follows

$$t_{V_H} = \left\{\frac{\sigma_y^{(old)}}{a\ U_{min}^p}\right\}^{1/p} \quad \text{and} \quad d_{V_z} = \left\{\frac{\sigma_z^{(old)}}{b\ U_{min}^q}\right\}^{1/q} \quad \text{in SIGMA1} \qquad (6.4)$$

$$t_{V_H} = \left\{\frac{\sigma_y^{(old)}}{a\ U_{min}^b}\right\}^{1/b} \quad \text{and} \quad d_{V_z} = \left\{\frac{\sigma_z^{(old)} - f}{c\ U_{min}^d}\right\}^{1/d} \quad \text{in SIGMA2} \qquad (6.5)$$

2 New Values of σ's are obtained by following expression corresponding to $(t_V + \Delta t)$

$$\sigma_y(t+\Delta t) = a\, U_{min}^{p} (t_{V_H} + \Delta t)^p \text{ and } \sigma_z(t+\Delta t) = b\, U_{min}^{q} (t_{V_z} + \Delta t)^q$$

(in SIGMA1) (66)

or

$$\sigma_y(t+\Delta t) = a\, U_{min}^{b} (t_{V_H} + \Delta t)^b \text{ and } \sigma_z(t+\Delta t) = b\, U_{min}^{d} (t_{V_z} + \Delta t)^d + f$$

(in SIGMA2) (67)

Dry and wet deposition Both dry and wet deposition for the pollutant are simulated by first-order reaction schemes and are computed during each Δt by an exponential reduction of the pollutant mass

$$M^{(new)} = M^{(old)} \exp [- P_j \Delta t/360,000] \quad (68)$$

Here j indicates dry (j=1) or wet(j=2) deposition and P_j is the corresponding percentage of reduction per hour (%/hr) P_1 and P_2 can be obtained from deposition velocity values and precipitation data as follows

$$P_1 = 360,000\ V_i/\Delta Z \text{ and } P_2 = S\ P_r/(10\ T_P) \quad (69)$$

where V_i is the current pollutant deposition velocity (m/s) at element's location, ΔZ is the vertical thickness of the puff ($\Delta Z = 2\ \sigma_z$), S is the pollutant scavenging ratio, P_r is the current precipitation rate at element's location (mm/hr) and T_p is the current thickness (m) of the precipitation layer at element's location Dry deposition is considered only when the plume has reached the ground (i e $2\ \sigma_z > H-ZR$)

Chemical transformation During each Δt, a first-order chemical reaction scheme is adopted, in which the chemical transformation term reduces the mass of pollutant in each puff according to

$$M^{(new)} = M^{(old)} \exp (- K\ \Delta t/360,000) \quad (610)$$

where K is the pollutant chemical transformation factor expressed as a percentage of reduction per hour (%/hr)

Concentration computation The concentration contribution (ΔC) of a single puff at a point (receptor) is basically computed by Eq 6 11 using current values of the puffs's variables M, σ_y, σ_z

$$\Delta C = \frac{M}{(2\pi)^{3/2}\,\sigma_y^2\,\sigma_z}\exp\left\{-\frac{(CPX-XR)^2}{2\sigma_y^2}\right\}$$

$$\exp\left\{-\frac{(CPY-YR)^2}{2\sigma_y^2}\right\}\quad\exp\left\{-\frac{(CPZ-ZR)^2}{2\sigma_z^2}\right\} \qquad (6.11)$$

The ΔC value is computed only if it is significant (i e > 0 001 $\mu g/m^3$) This is ensured by comparing the ratio $(D/\sigma)_1$ (computed using Eq 6 11 by substituting ΔC=0 001 $\mu g/m^3$, $\sigma_y = \sigma_z$, and appropriate puff and receptor coordinates) and $(D/\sigma)_2$ (ratio of the direct distance between puff and receptor to σ_y or σ_z, whichever is greater) If $(D/\sigma)_2 > (D/\sigma)_1$, ΔC is set to zero Eq 6 11 is expanded with a reflection term (similar to that in Eq 5 9) whenever $2\sigma_z >$ CPZ-ZR

Puff splitting Breaking of a plume into puffs allows the evaluation of their dynamics as a function of local time-varying meteorological conditions In particular, during each Δt, the centre point of each puff moves from an old to a new position (advective displacement) Large advective displacement due to an increase in wind speed may affect puff's ability to represent the continuous plume by reducing resolution The splitting technique (Zannetti, 1981), which generates, when required, a sufficient number of fictitious puffs along the puff's trajectory during Δt to maintain sufficient resolution, is used This splitting of puff is performed for computing ΔC when (1) ΔC>0, and (2) advective displacement $\geq 1.5\,\sigma_y$ In this splitting computation mass M of the puff is equally distributed among the split puffs along the trajectory from the old position to the new one σ_y and σ_z values for the fictitious puffs are interpolated linearly between the respective σ values at the puff's old and new centre point

Computer programme using PUFF formulation Main objective of this programme is to predict time dependent point concentration of a pllutant released from non-steady source under essentially

calmwind conditions The programme named "PUFFS" consist of several subprogrammes (Fig 6 1) and its logic is schematically presented in Fig 6 2 Following are some salient features of this programme

1 Entire region of source influence is divided into meteorological grid considering the source to be situated at the centre of the left edge of the middle row Hence, there will always be odd number of rows in the grid Each block of the grid is allowed to take different meteorological parameters after every time step

2 The plume profile specifies puff number, its centre point coordinates, pollutant mass contained in it and the corresponding dispersion standard deviations

3 Loss of pollutant due to chemical reaction or dry/wet deposition is computed assuming a first order reaction scheme at every puff generation time step

4 Concentration computations are carried out at user specified time interval This implies that the subprogramme CONCTR is called only when concentration values are required

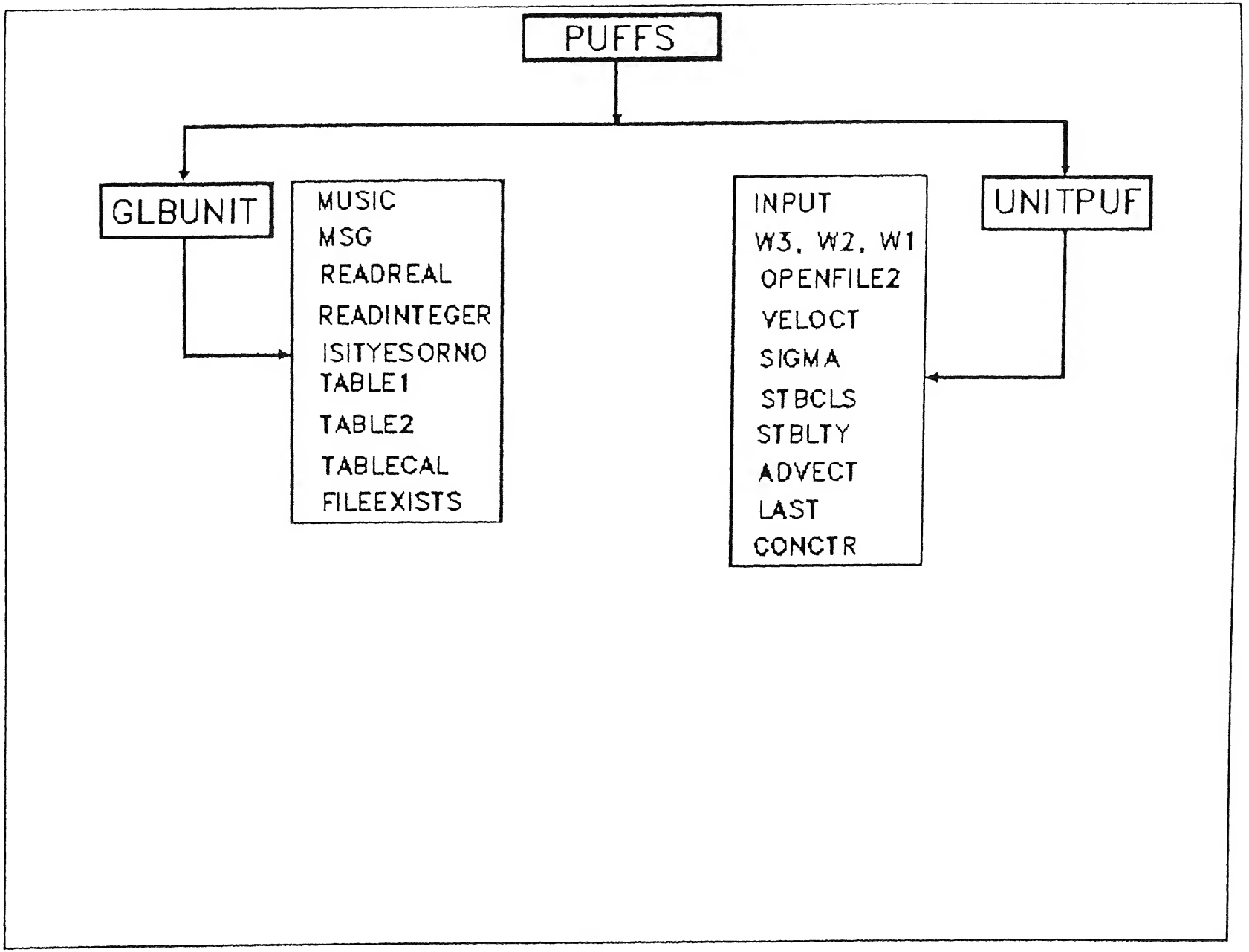
5 To avoid excessive computational efforts, maximum number of fictitious puffs is restricted to 50 Further to check floating underflow errors, exponential terms are set to zero whenever the exponent becomes less than -25

Subprogrammes VELOCT, STABCLS, BOUYNC, W3, W2, W1 and OPENFILE2 are same as used in UNISDGTL OR UNISGRF A brief description/function of other subprogrammes is as follows

(1) INPUT The data read through input file (INP3) are as follows

a Source - same as in "UNISDGTL"

b Meteorology - In addition to the data read in "UNISDGTL", other data those are to be read are the angle of wind velocity vector in the vertical and horizontal plane from x axis, deposition index (1 for dry and 2 for wet), the rate of


PUFFS
GLBUNIT
MUSIC
MSG
READREAL
READINTEGER
ISITYESORNO
TABLE1
TABLE2
TABLECAL
FILEEXISTS
UNITPUF
INPUT
W3, W2, W1
OPENFILE2
VELOCT
SIGMA
STBCLS
STBLTY
ADVECT
LAST
CONCTR

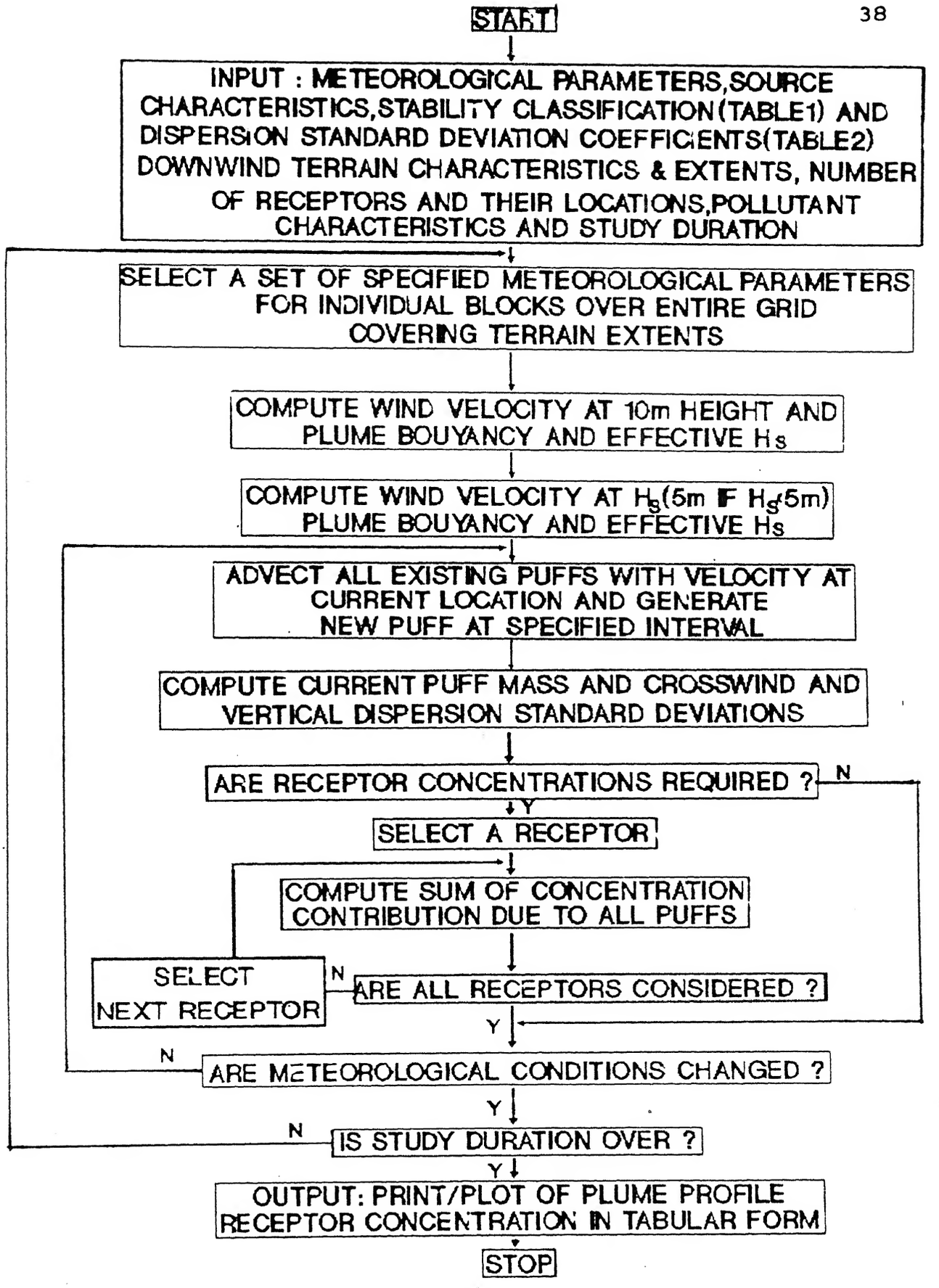


Fig. 6.2 Schematic representation of the logic adopted in programme "PUFFS"

precipitation, pollutant deposition velocity and thickness of precipitation layer. These data are to be provided for every block of the grid and for every meteorological time step. Instrument minimum wind velocity is used as a criteria to determine calmwind conditions.

c. Domain of the grid - Maximum values in the x and y directions with the corresponding block size.

d. Receptors - number of receptors and their coordinates.

e. Time variables - maximum time of influence, meteorological time step, concentration calculation and puff generation interval.

f. Other - pollutant scavenging ratio, chemical transformation factor for the pollutant, coefficient of reflection from ground.

(2) STBLTY. It finds out the stability class for every block of the grid at every meteorological time step on the basis of Pasquill stability classification.

(3) SIGMA. This subprogramme is used to compute dispersion standard deviations. The only modification over that used earlier (e.g. in RECPCONC) is that the virtual distance (transport conditions) virtual age (calmwind conditions) concept is used whenever meteorological (i.e. stability class) is different at puff's new and old centre point either due to non-stationary or inhomogeneous conditions of the atmosphere (Section 6.2).

(4) ADVECT. Advection of each puff during a period is done through this subprogramme. Wind velocity vector at the present location of the puff centre is computed and then it is advected to the new location, hence, it finds out the new coordinates and the block index in which it is located.

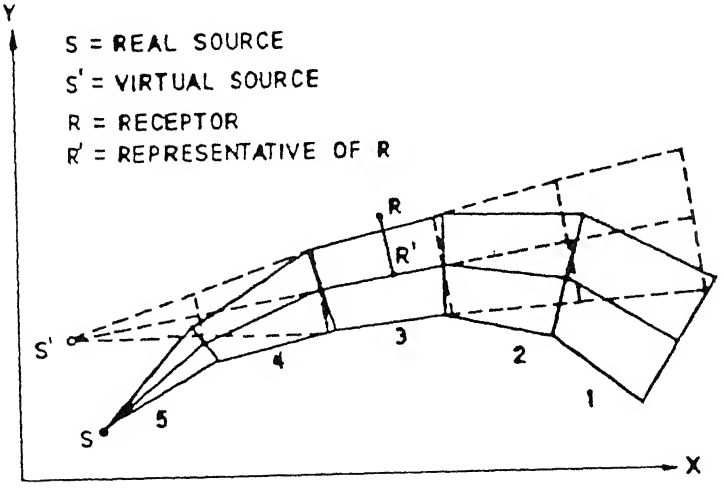
(5) LAST. It assigns the characteristics to the newly born puff, e.g. the coordinates, dispersion standard deviations and mass.

(6) CONCTR· It computes the concentration contribution to receptor by every puff Only those puffs contributin significantly to a receptor are considered If the effectiv legnth of the puff is greater than 15 σ_y, then puff splitting i adopted to maintain sufficient resolution, in which the puff i assumed to be an aggregation of a number of virtual puffs, thei characteristics are computed by linear interpolation, and puf mass is divided equally among the splitted puffs Aggregat contribution of all the puffs is reported as the fina concentration at a receptor

6.3 SEGMENT Formulation

The segment apporoach was basically developed to remov limitations of steady-state formulation while maintainin simplicity of the Gaussian theory The segmented plume mode (Benkley and Bass, 1980; Chen *et al*, 1979, Hales *et al*, 1977 which is dynamic and considers non-steady state conditions however, still requires transport conditions (U $\geq$ 1m/s)

Segment method breaks the plume into independent segments whose initial features and dynamics are a function of local time-varying emissions and meteorological conditions Therefore, it is able to stimulate non-stationary an inhomogeneous dispersion conditions Segments are considered as sections of a Gaussian plume Each segment generates a concentration field which is still basically computed by Eqs 5 7 - 5 9, and represents the contribution of the entire virtual plume passing through that segment as illustrated in Fig 6 3



Therefore, only one segment (the closest) affects the concentration computation at each receptor Dynamics of each segment is similar to that of each puff except that the segment is characterized by two points (leading and trailing) on the segmented plume as follows

1 Coordinates of the leading point CPX(IFS), CPY(IFS), CPZ(IFS)

2 Coordinates of the trailing point CPX(ISS), CPY(ISS), CPZ(ISS)

3 Standard deviations of the Gaussian concentration distribution σ_y(IFS), σ_y(ISS), σ_z(IFS) and σ_z(ISS)

The procedure adopted for (1) the generation of segmented plume, (2) advection, (3) diffusion, (4) dry and wet deposition, and (5) chemical transformation is same as described in Sec 6 2 However, the concentration contribution due to a segment is computed as follows

Concentration computation The concentration computation due to a segmented plume requires identification of the segment closest to the receptor R and utilization of the segment's variables for computing, using basically Eqs 5 7 and 5 9, the concentration field generated by the equivalent plume passing through that segment (Fig 6 3) The parameters in Eqs 5.7 and 5 9 are evaluated in the following way

1 Segment's variables (σ_y, σ_z, elevation) are evaluated at the point R' (base of the prependicular drawn from the receptor on the centre line of the closest segment, Fig 6 3) Evaluation of σ_y and σ_z is done by linear interpolation (or extrapolation if R' lies outside the first and second point of the closest segment) using respective σ(IFS) and σ(ISS) values

2 Q is evaluated as virtual current emission rate i e $Q = M/\Delta t$

3 Wind velocity is evaluated at R' according to Eq 5 13 taking atmospheric conditions at R' location

Identification of Closest Segment The segment closest to the receptor is identified in following steps

Step 1 Distance D_1 and D_2 of the first and second point of the leading segment are computed as follows

$$D_1 = [(CPX(IFS)-XR)^2+(CPY(IFS)-YR)^2+(CPZ(IFS)-ZR)^2]^{1/2} \quad (6\,12)$$

$$D_2 = [(CPX(ISS)-XR)^2+(CPY(ISS)-YR)^2+(CPZ(ISS)-ZR)^2]^{1/2} \quad (6\,13)$$

Step 2 If $D_1 \geq D_2$ the current segment is taken as closest segment or else D_1 is equated to D_2 and D_2 is recomputed using Eq 6 12 for the following segment

Step 3 Step 2 is repeated until the last segment and if no segment satisfies the condition of Step 2, the last segment is taken as the closest segment

Evaluation of segment parameters Evaluation of segment parameters for concentration computations is done for closest segment at R' (Fig 6 3) This is done in following way

1 Evaluate the effective length (EFL) and direction cosines (SL, SM and SN) of the centre line of the closest segment

$$EFL = [(CPX(IFS)-CPX(ISS))^2+(CPY(IFS)-CPY(ISS))^2 + (CPZ(IFS)-CPZ(ISS))^2]^{1/2} \quad (6\,14)$$

$$SL = (CPX(IFS) - CPX(ISS))/EFL \quad (6\,15)$$

$$SM = (CPY(IFS) - CPY(ISS))/EFL \quad (6\,16)$$

$$SN = (CPZ(IFS) - CPZ(ISS))/EFL \quad (6\,17)$$

2 Evaluate the projection of the line joining second point of the closest segment to the receptor (T) along segment's centre line

$$T = SL(XR-CPX(ISS))+SM(YR-CPY(ISS))+SN(ZR-CPZ(ISS)) \quad (6\,18)$$

3 The coordinates of R' are computed as

$$SXR = CPX(ISS) + SL * T \quad (6\,19)$$

$$SYR = CPY(ISS) + SM * T \quad (6\,20)$$

$$SZR = CPZ(ISS) + SN * T \quad (6.21)$$

4 The σ_y and σ_z values at R' point are given by

$$\sigma_y \text{ at } R' = S_{\sigma_y} = \sigma_y(ISS) + (\sigma_y(IFS) - \sigma_y(ISS)) \frac{T}{EFL} \quad (6.22)$$

$$\sigma_z \text{ at } R' = S_{\sigma_z} = \sigma_z(ISS) + (\sigma_z(IFS) - \sigma_z(ISS)) \frac{T}{EFL} \quad (6.22)$$

Computer programme using SEGMENT formulation Main function of this programme is to predict time dependent point concentration of a pollutant released from non-steady source under transport conditions The programme named "SEGMNT" consist of various subprogrammes (Fig 6.4) and its logic is schematically presented in Fig 6.5 The programme features are similar to that of "PUFFS" except the procedure for computing receptor concentration Further, if the receptor is not covered by the region of influence (SXR > XR) of the segmented plume or dispersion parameters evaluated at R' point are negative or zero, concentration contribution due to entire segmented plume is set to zero

6.4 Mixed PUFF-SEGMENT formulation

The mixed PUFF-SEGMENT is a recently developed approach (Zannetti, 1986), in which plume is described by a series of elements, may be segments or puffs, or both The type of element affects computation of concentration field However, element dynamics remains unchanged (Sec 6.3) This approach is more suited for lightwind conditions and can work in both calmwind and transport conditions

Identification of element type The element type is a key factor in computing the plume concentration field The criteria for identifying the type of element is the ratio between its projected length on horizontal plane D_H (i.e the horizontal distance between the first and second point of the element) and σ_y For a segment

$$D_H/\sigma_y > 2 \quad (6.24)$$

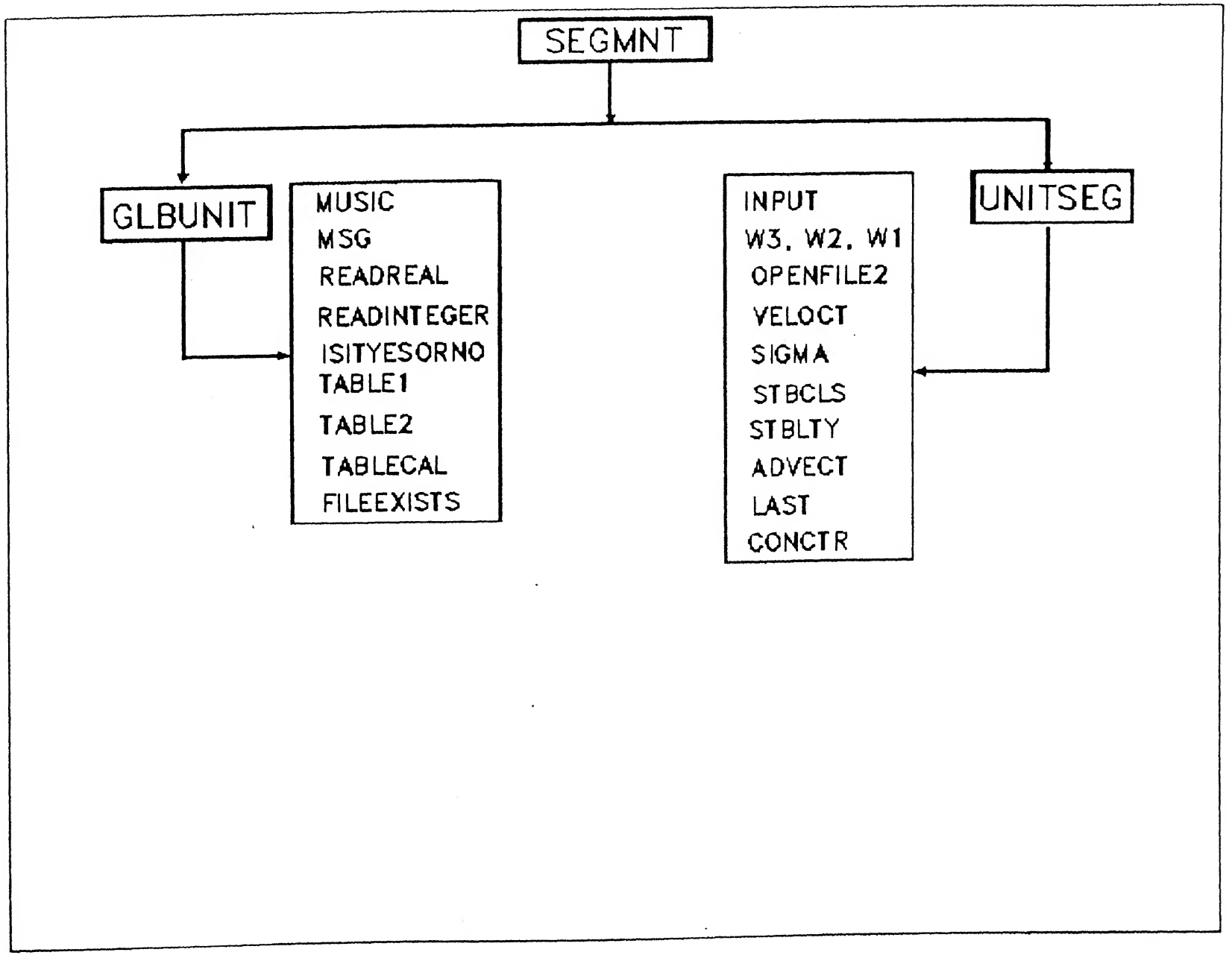


Fig. 6.4 Programme tree for SEGMNT

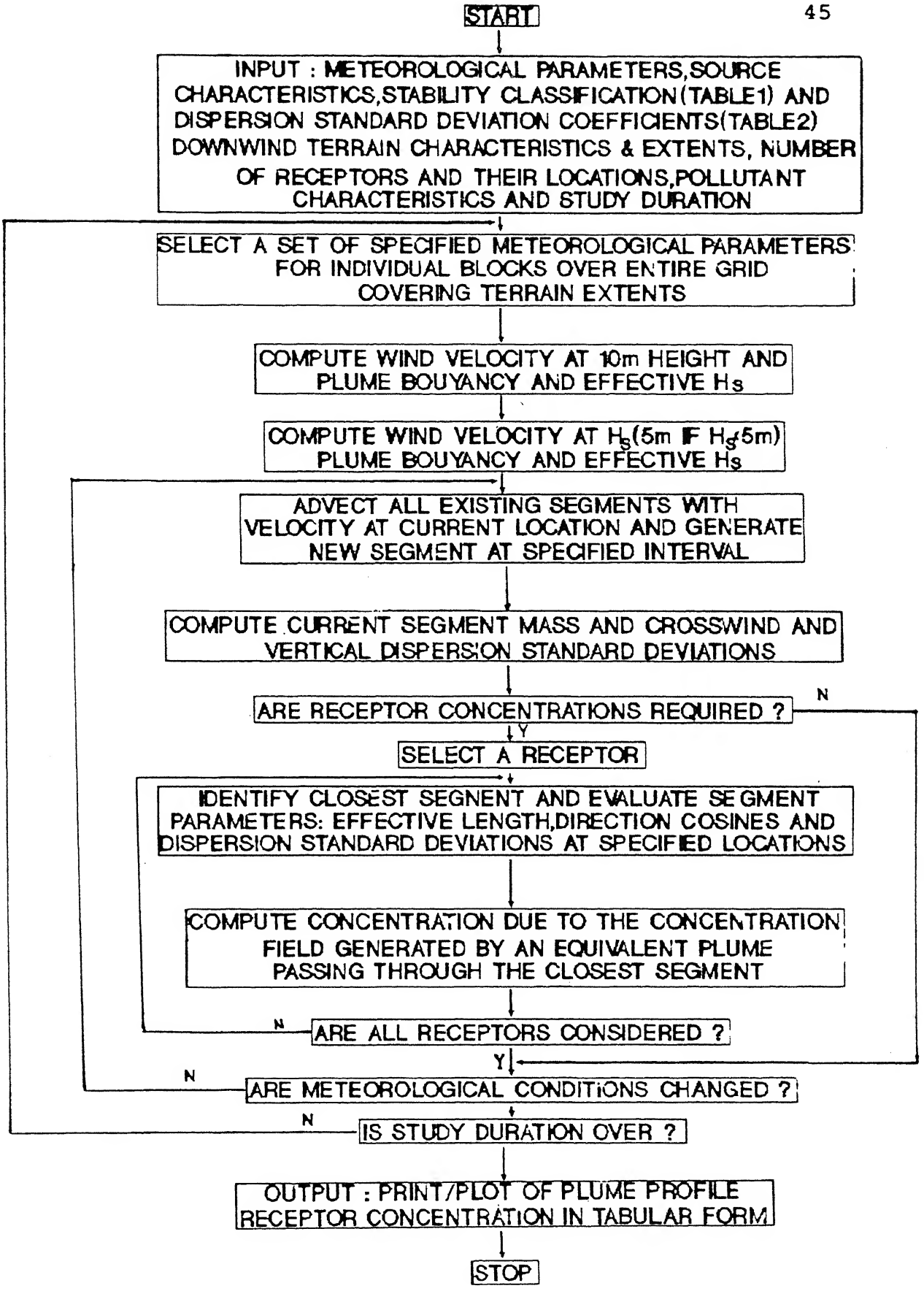


Fig. 6.5 Schematic representation of the logic adopted in programme 'SEGMNT'

and, for a puff,

$$D_H/\sigma_y \leq 2 \qquad (6.25)$$

Here σ_y value is taken as average of σ_y(IFS) and σ_y(ISS) Since σ_y continues to grow with time, all segments will eventually become puffs.

The aforementioned criteria assures that, when segments are transformed into puffs, the distance D_H between two consecutive puffs will not be greater than $2\sigma_y$, which is the condition required (Ludwig *et al*, 1977) for a series of puffs to provide an almost perfect representation of a continuous plume In calmwind conditions, $D_H \cong 0$ and puffs are generated directly from the source

Concentration computation The concentration at a receptor R due to a certain source S must account for the contribution of all elements generated from S Thus the total concentration at any receptor is the sum of the contributions of all the existing puffs plus the contribution of the closest segment

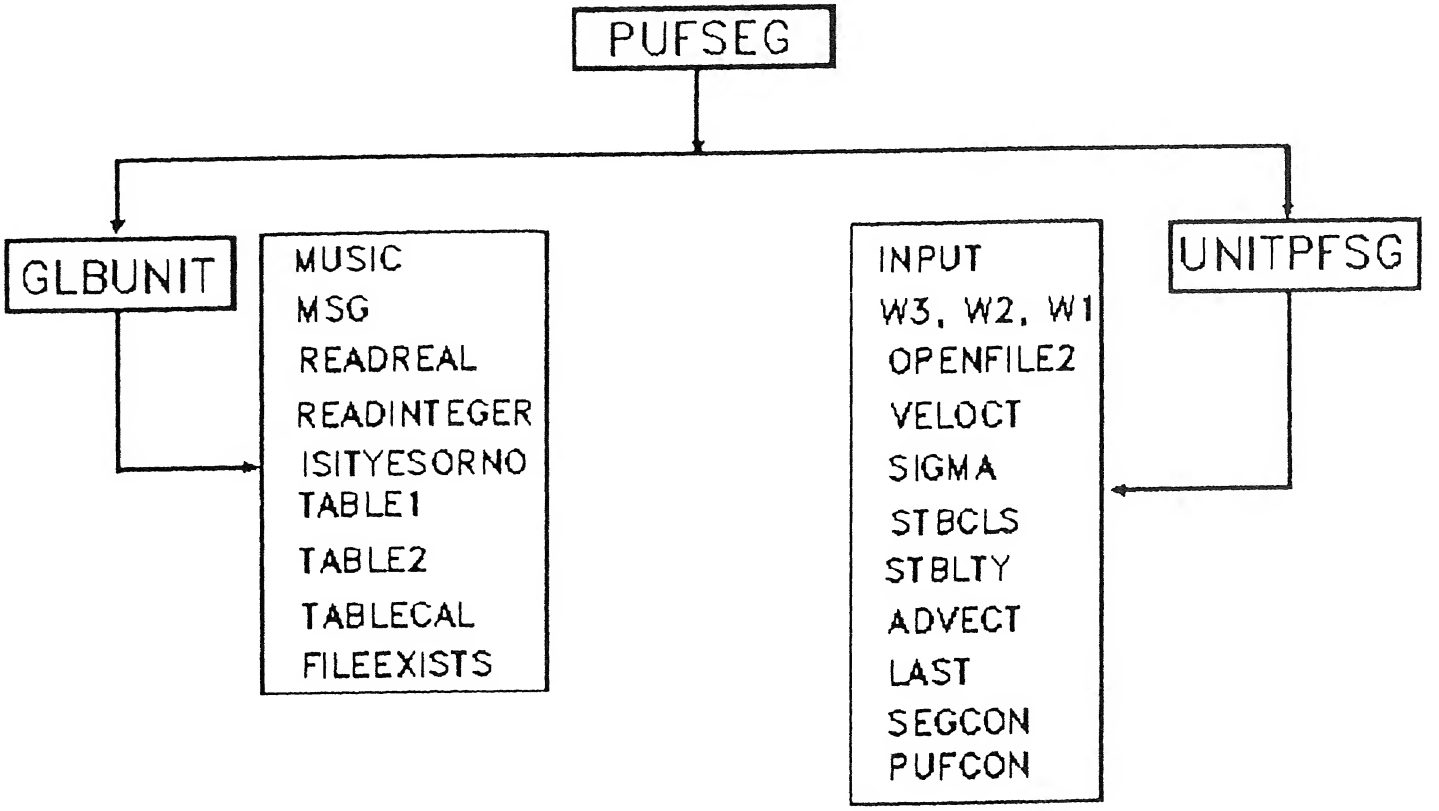
A Puff Contribution The concentration contribution of a single puff at a receptor R is basically computed as indicated in Sec 6 2 However, the σ's are evaluated at the centre point of the element (Puff) as follows

$$P_{\sigma_y} = \frac{\sigma_y(IFS)+\sigma_y(ISS)}{2} \text{ and } P_{\sigma_z} = \frac{\sigma_z(IFS)+\sigma_z(ISS)}{2} \qquad (6.26)$$

Puff splitting is adopted whenever $D_H > 1.5\ \sigma_y$ The splitting procedure is same as in Sec 6 2

B Segment Contribution Contribution of only the closest segment, which surrogates the effect of all other segments, is computed as described in Sec 6 3

Computer programme for Mixed PUFF-SEGMENT formulation Main function of this programme is to predict time dependent point concentration of a pollutant released from non-steady source under lightwind conditions The programme named "PUFSEG" consists of several subprogrammes (Fig 6 6) and its logic is schematically


PUFSEG
GLBUNIT
MUSIC
MSG
READREAL
READINTEGER
ISITYESORNO
TABLE1
TABLE2
TABLECAL
FILEEXISTS
UNITPFSG
INPUT
W3, W2, W1
OPENFILE2
VELOCT
SIGMA
STBCLS
STBLTY
ADVECT
LAST
SEGCON
PUFCON

presented in Fig 6 7 The basic structure of the programme is similar to that of "SEGMNT" except for the following changes

1 The plume consist of elements which may be segments or puffs Thus it requires identification of elements and segregation in two diffeent series of puffs and segments

2 It requires checking continuity of segment series for identification of closest segment

3 Though the procedure for σ evaluation is same for all elements (puffs or segments, Fig 6 7), the points of evaluation are different with reference to physical location of the elements For puffs σ's are evaluated at centre point of the element while for segments at R' location

4 The concentration contribution due to closest segment is computed first in subprogrammes SEGCON and to that is added the contribution of all the puffs to get total point concentration at a receptor Segment contribution is computed only if the receptor comes in the influence region of the segment portion of the plume (x coordinate of the first point of the leading segment > XR)

5 The output gives complete plume profile specifying the type of elements

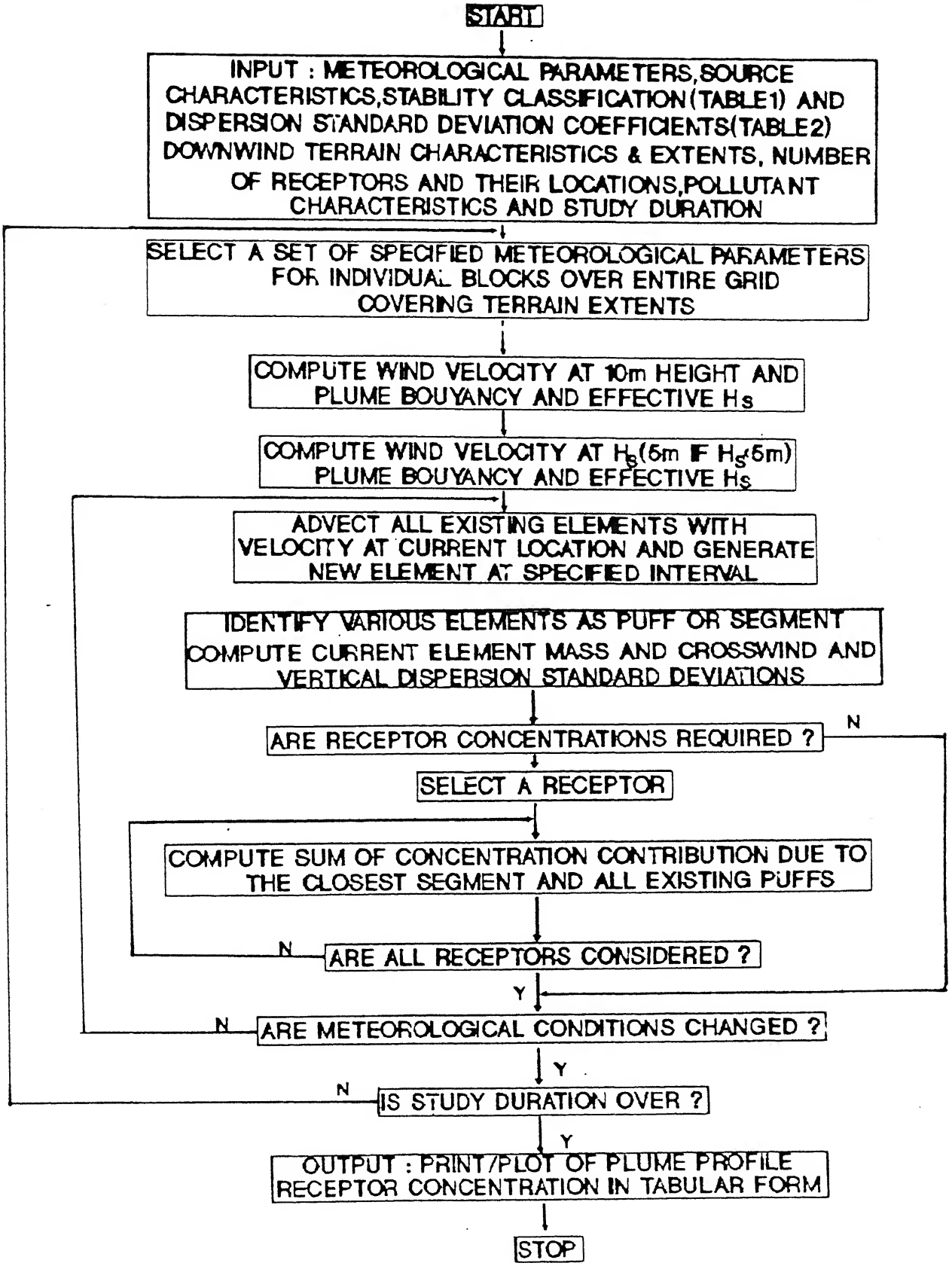


Fig. 6.7 Schematic representation of the logic adopted in programme "PUFSEG"

7 PACKAGE OPERATION AND VALIDATION OF RESULTS

7 1 Package Operation

The loading and compiling to disks of various programmes through TURBO PASCAL version 4 0 on any IBM PC compatible create files with extension TPU/EXE which can then be executed in MS DOS environment without entering into TURBO However, some of the TURBO PASCAL files (list given in Appendix I) must be available on the disk directory of the package The execution of the package programmes requires a batch file which in itself can be considered as a master programme (a set of DOS commands to execute various programmes constituting the package in a sequence determined by the user response) A listing of INDISPOL batch file is presented in Appendix II The package execution starts with a command

C>INDISPOL

The package then displays first two cover pages (Figs 7 1 and 7 2, for convenience all figures in this chapter are placed in a sequence at the end of the chapter) and a PASSCODE option (Fig 7 3) The very first input the package requires is a package access code In the absence of the correct access code, the package cannot be opened/initialized Once the correct code has been identified, inside cover pages (Figs 7 4 and 7 5), general information about the package utilities (Fig 7 6 a &b), MENU HELP (Fig 7 7) and SELECTION MENU (Fig 7 8) are displayed in a series The screen is divided in four windows The top most window gives heading, the main window shows options available, the side window displays selections made and the bottom window indicates status of current operation and options for forward/backward movement within the package and transferring control to the hard copy terminal for printing screen displays

The selection of EDITOR option (Figs. 7.8 and 7.9) allows access to WORDSTAR 2000 (WS2000) and displays EDIT GUIDE (Fig.7.10). Exiting from the EDITOR mode returns the user to SELECTION MENU (Fig. 7.11).

User is now ready to select any simulation technique (UNIS, MULTYS, PUFFS, SEGMNT or PUFSEF) depending upon the requirement. However, the GUIDE option (Fig.7.12) enables user to know the features of various simulation techniques (Figs. 7.13-7.17). After the user has gone through the guidelines available, package control is transferred to the SELECTION MENU (Fig. 7.18) again. Selection of a simulation technique displays its suboptions (e.g. Fig. 7.19) until a terminal selection (Fig.7.20) is made. User can make multiple selections by choosing STAY (F2) option in which case the package returns to SELECTION MENU. Multiple selections are recorded in the sequence in which they are selected in a dummy file which permits sequential execution of various selections made. The selection NEXT (Fig. 7.20) results in execution of selected options.

The package has provision of displaying stability classification table and coefficients adopted in computing dispersion standard deviations using power laws (Fig.7.21). Typical results of selecting UNIS-DIGITAL and UNIS-GRAPHICAL for a specific input are presented in Figs. 7.22-7.25. In a similar way other simulation techniques can be selected. The package provides for repeatative selections after all current selections are executed by transferring control to SELECTION MENU, if required. All digital outputs can be stored in a user specified files which can be accessed from within or outside the package. Exit from the package after proper access results in display of end cover pages (Fig.7.26 and 7.27). A sample input/output for various simulation techniques adopted are presented in Appendices III to V.

7.2 Validation of Results

Validation and limitations of any simulation procedure must be checked before its application is made to a real world problem for decision-making. The simulation procedures were validated through a number of tests. These tests included checking

stability of the results, sensitivity of the simulation procedures to several variables defining the physics of the problem, comparison of the results with other simulation procedures and comparison of the simulation results with experimental/field measurements. In general predicted results were found to be quite logical and compared very well with those reported in earlier studies (Nema and Tare, 1989, Nema, 1987).

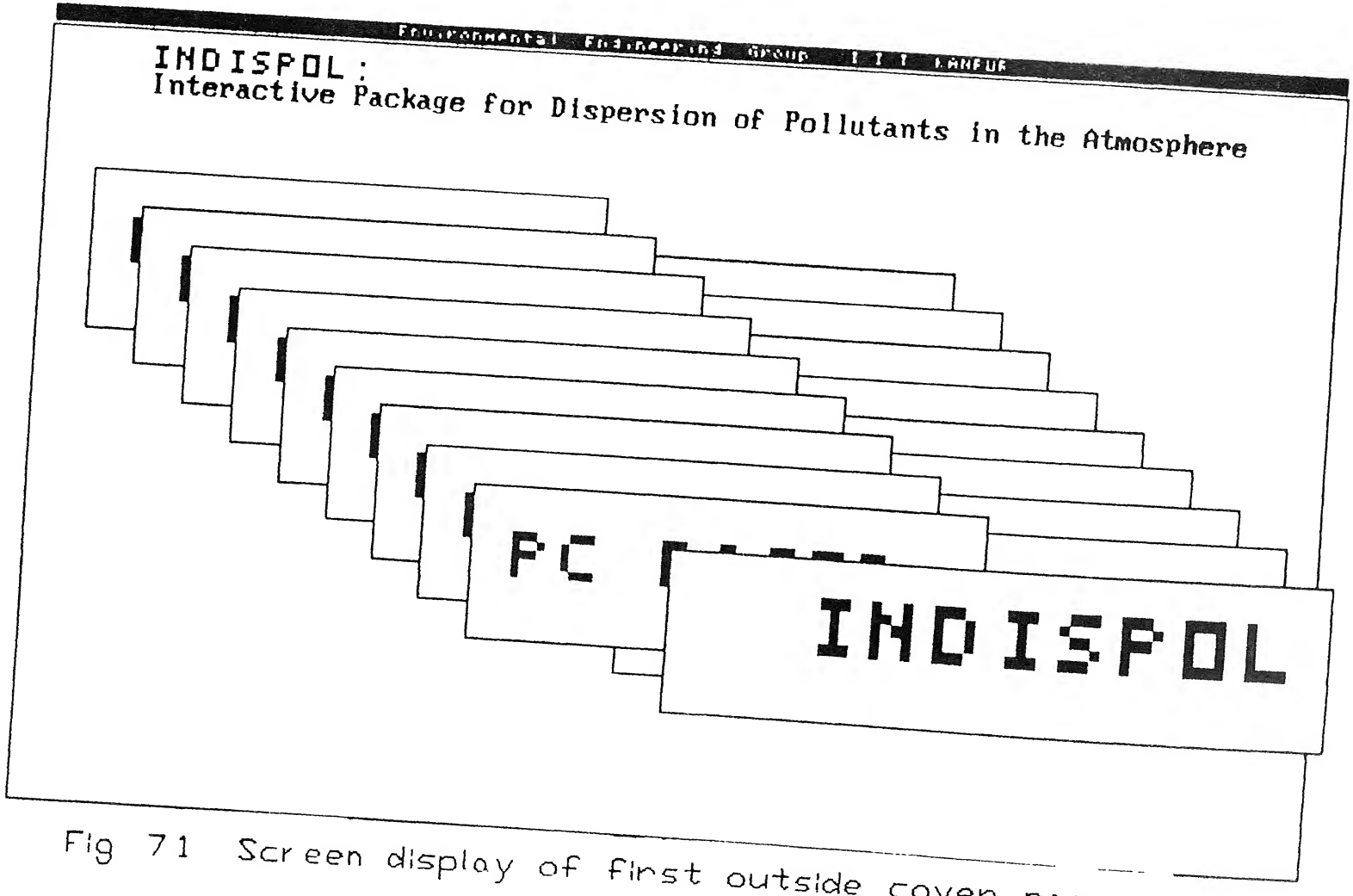


Fig 71 Screen display of first outside cover page

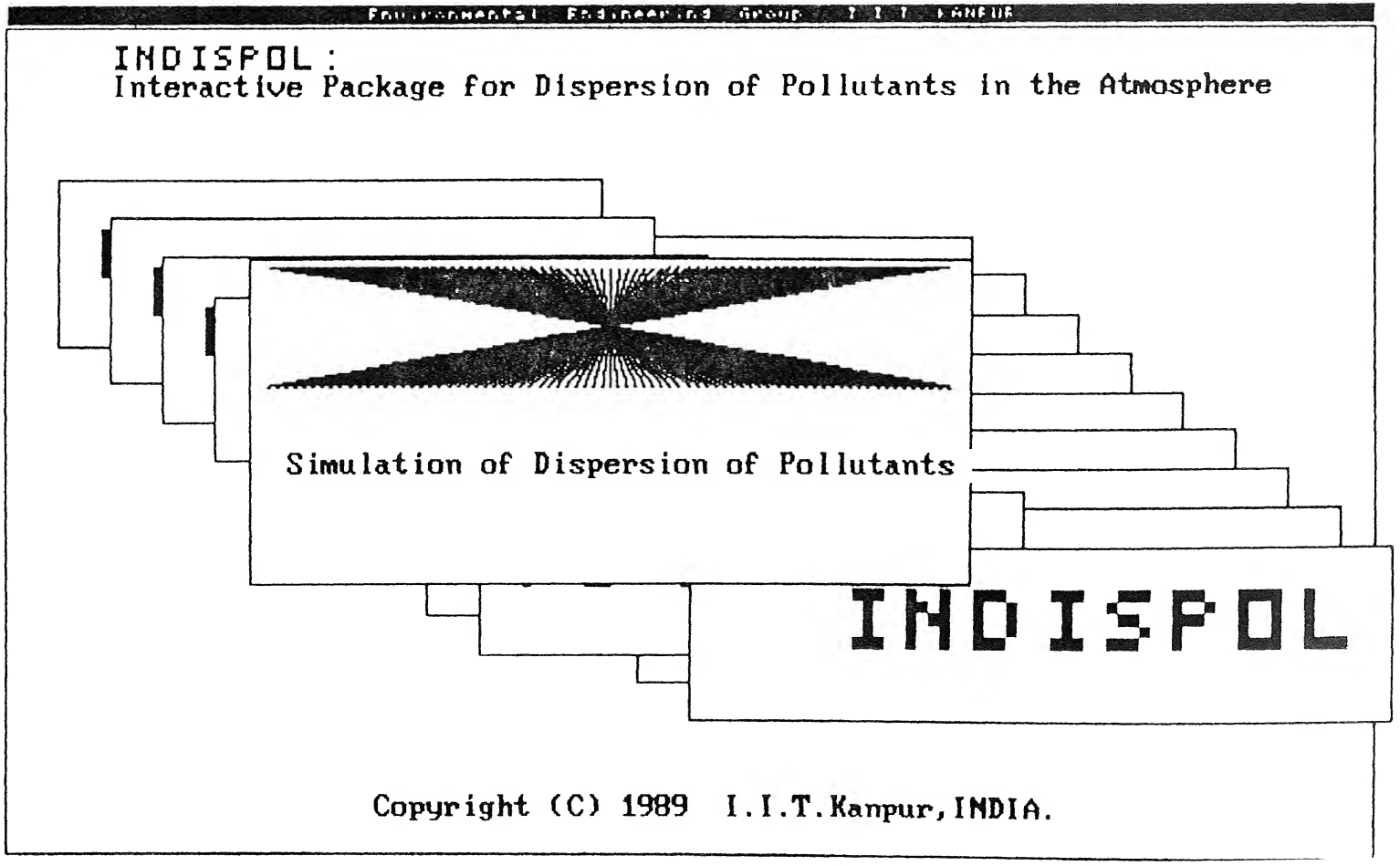


Fig. 7.2 Screen display of second outside cover page

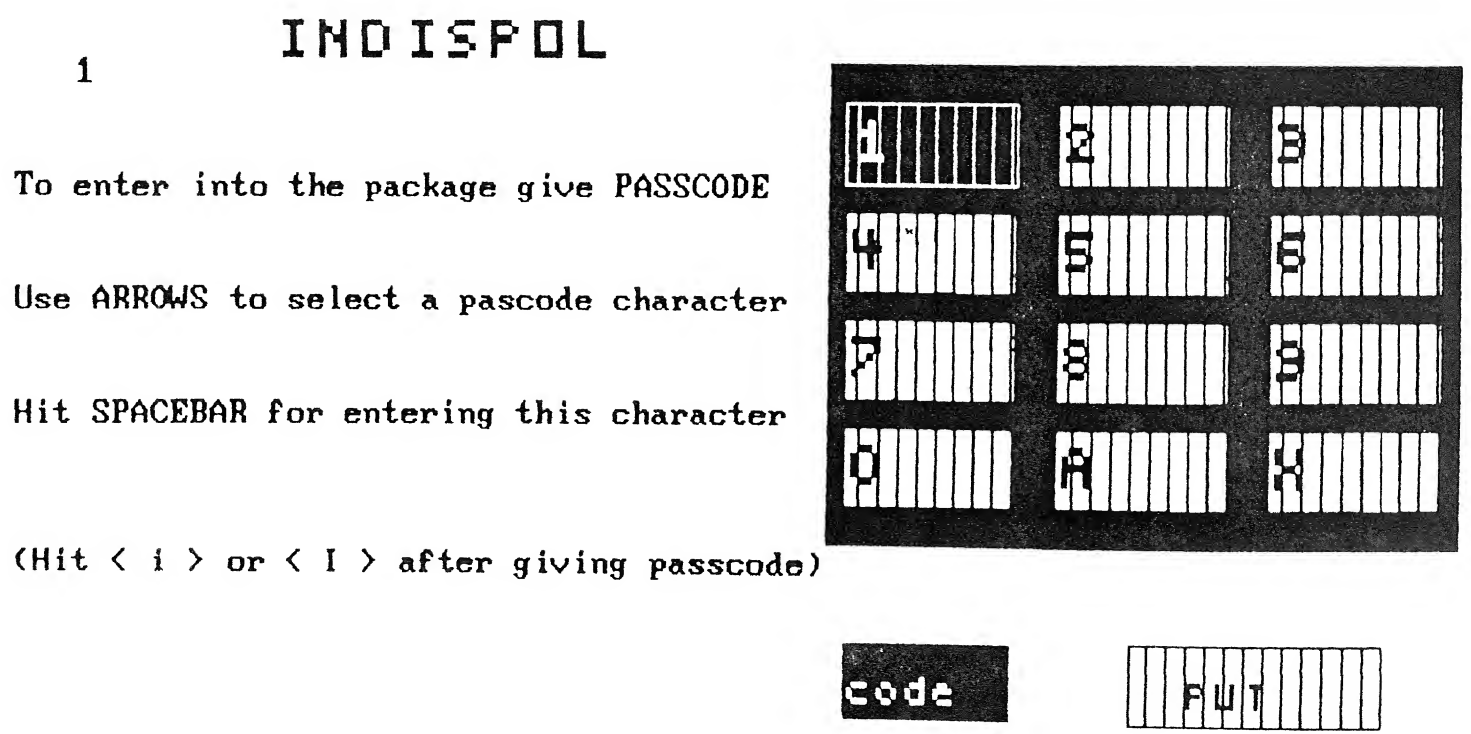


Fig. 7.3 Screen display of PASSCODE option

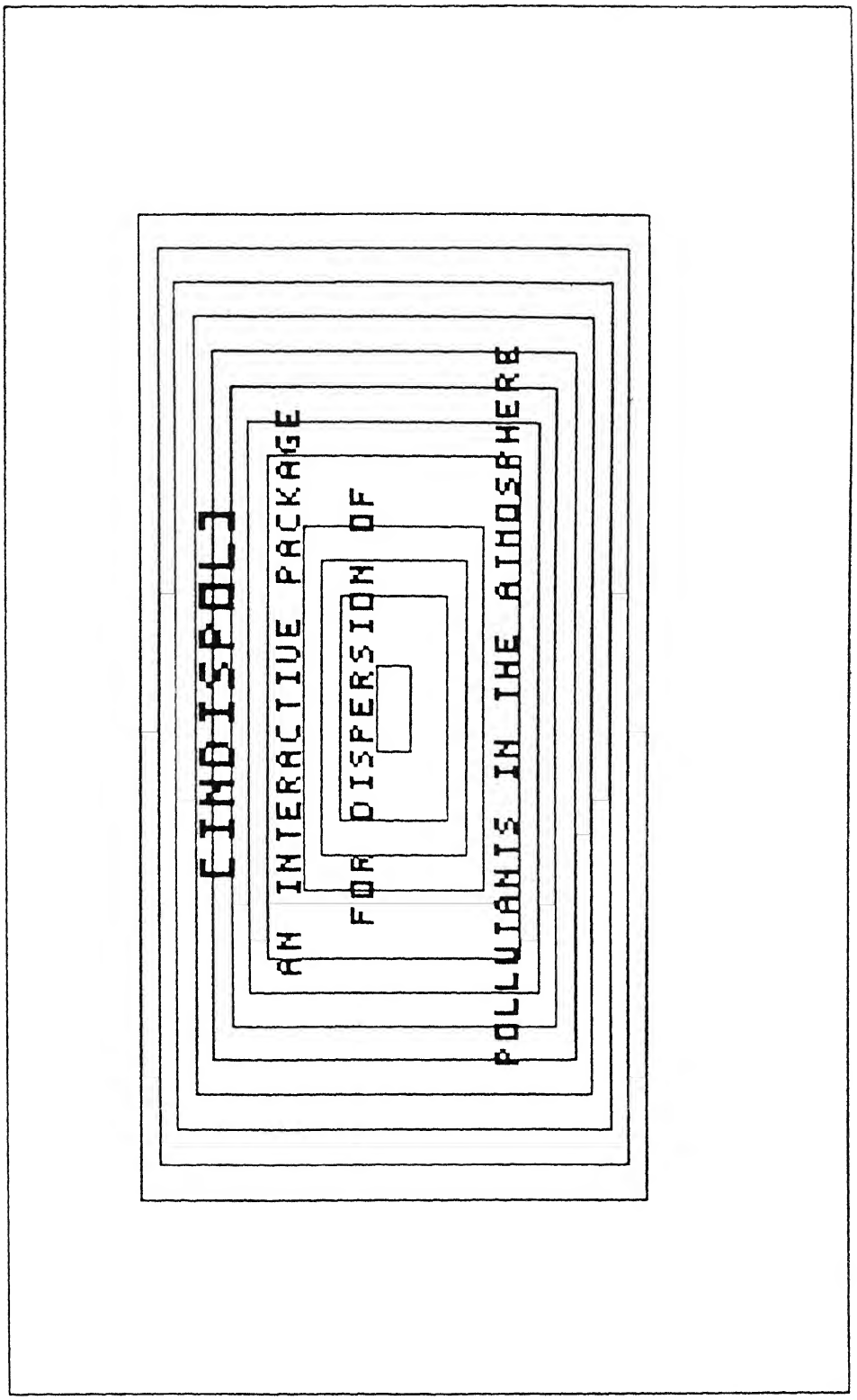


Fig. 7.4 Screen display of first inside cover page

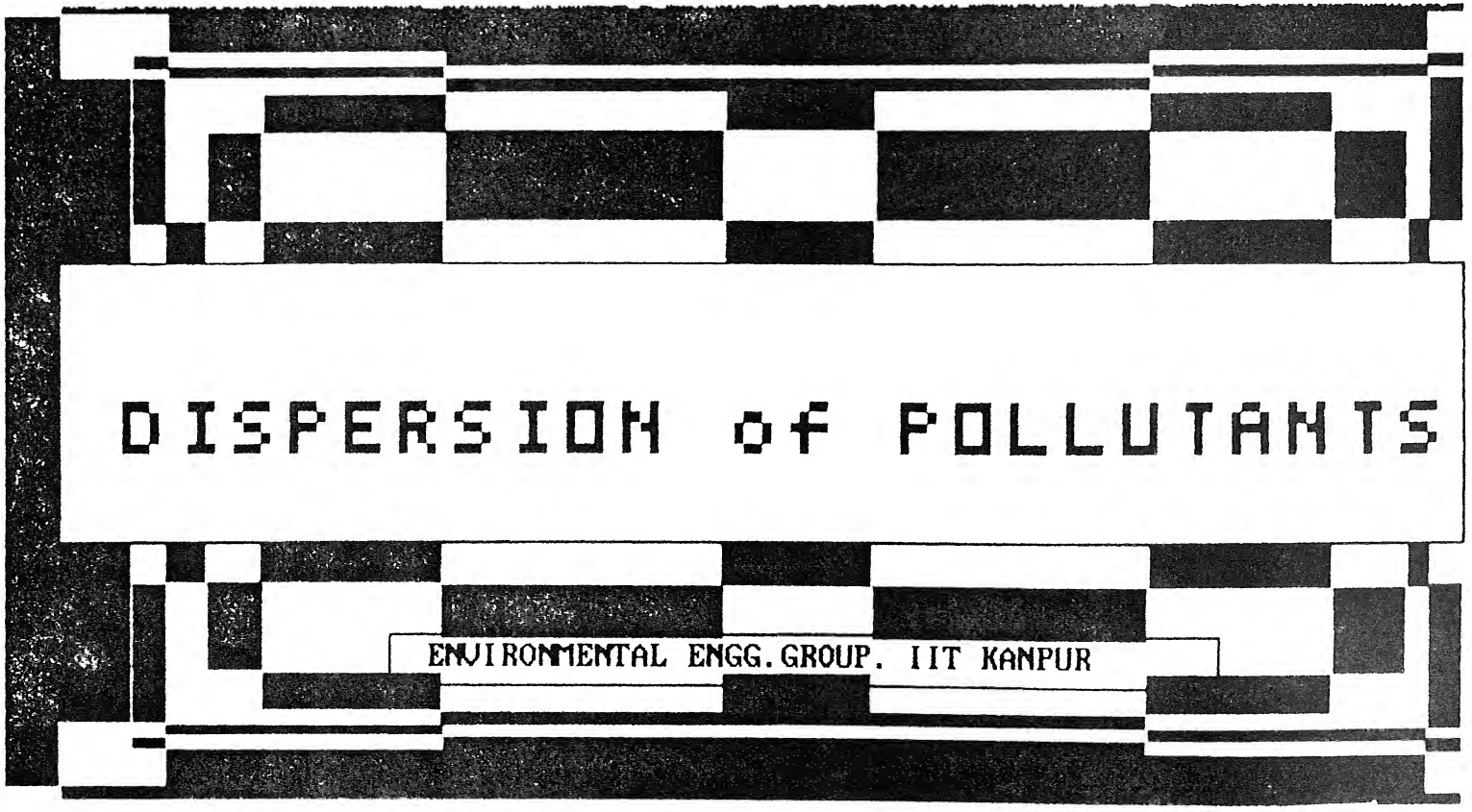


Fig. 7.5 Screen display of second inside cover page

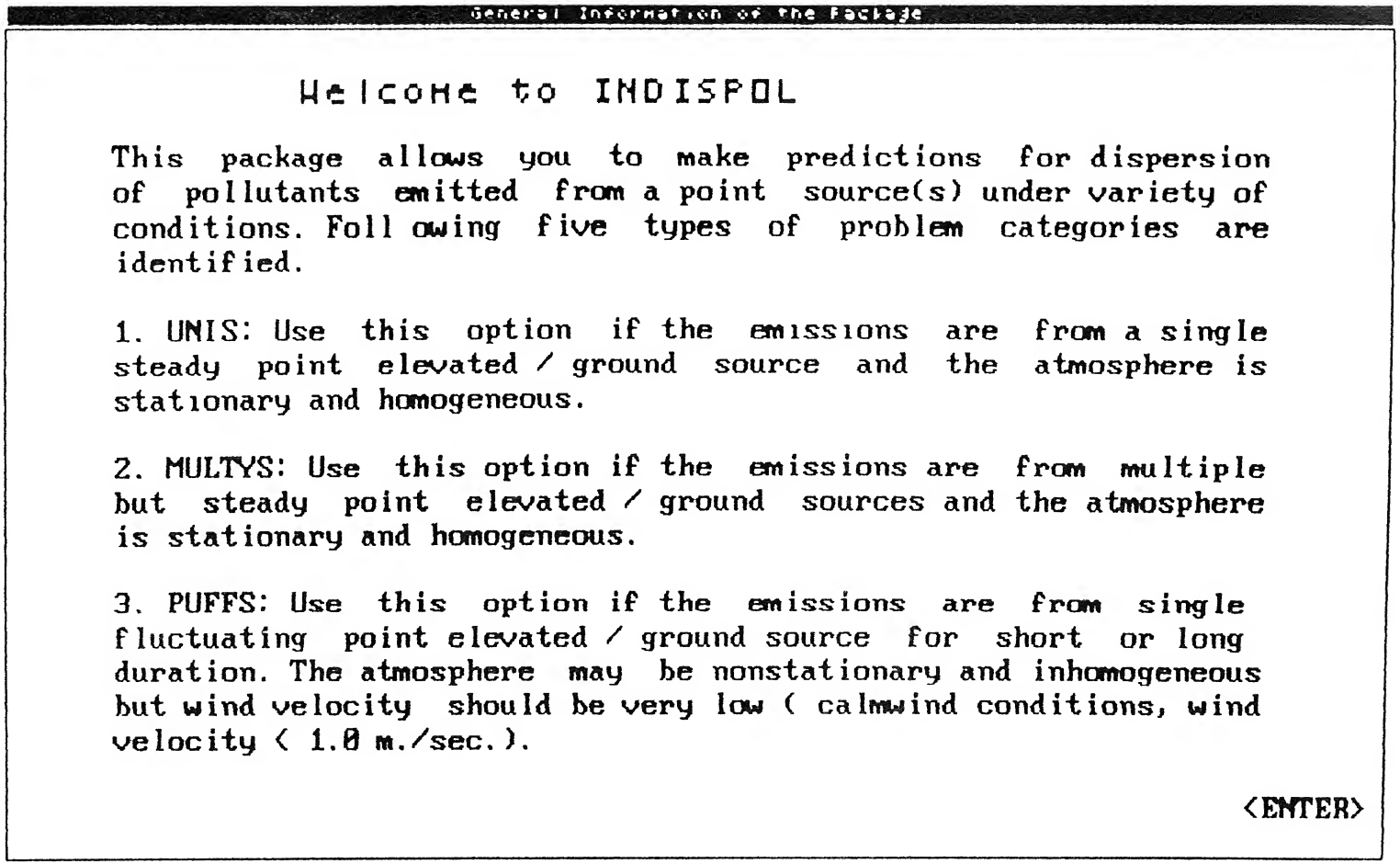


Fig. 7.6(a) Screen display of package general utilities - 1

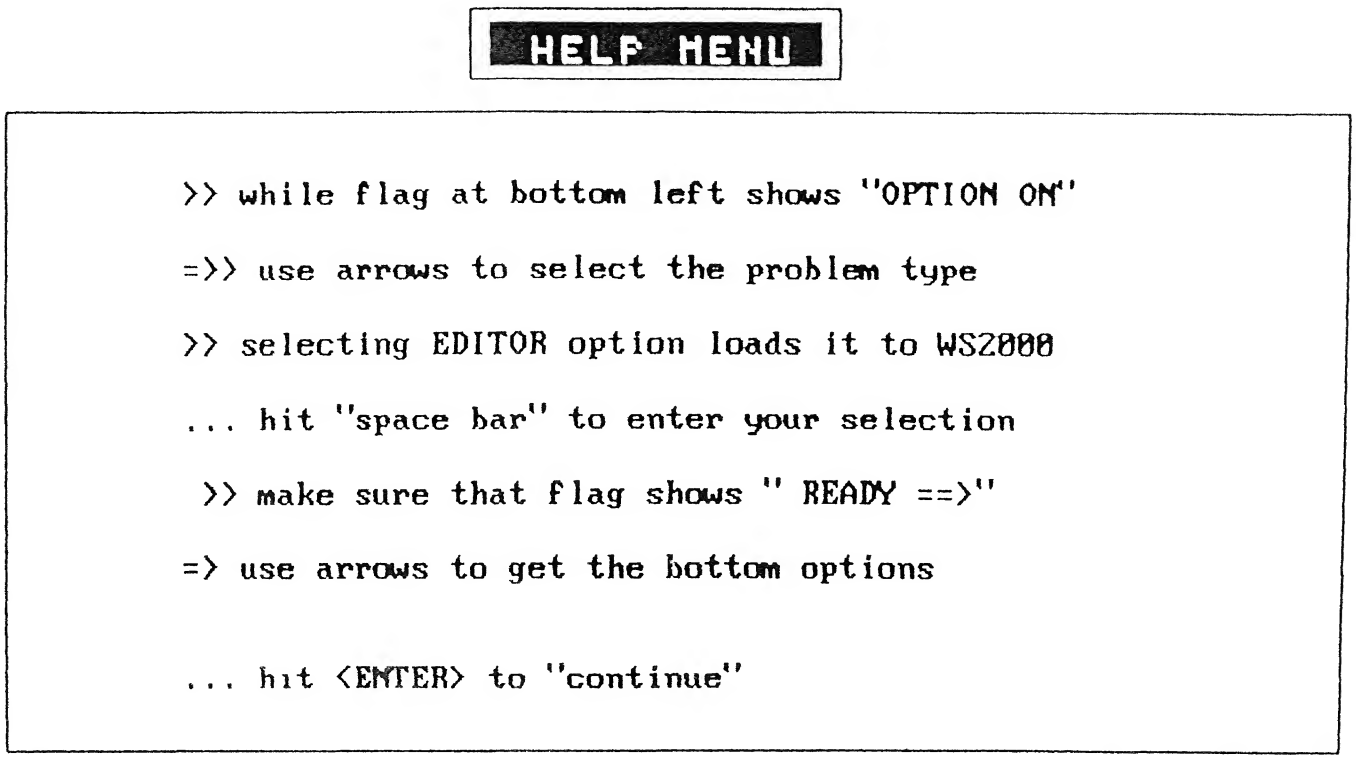


Fig. 7.7 Screen display of HELP MENU

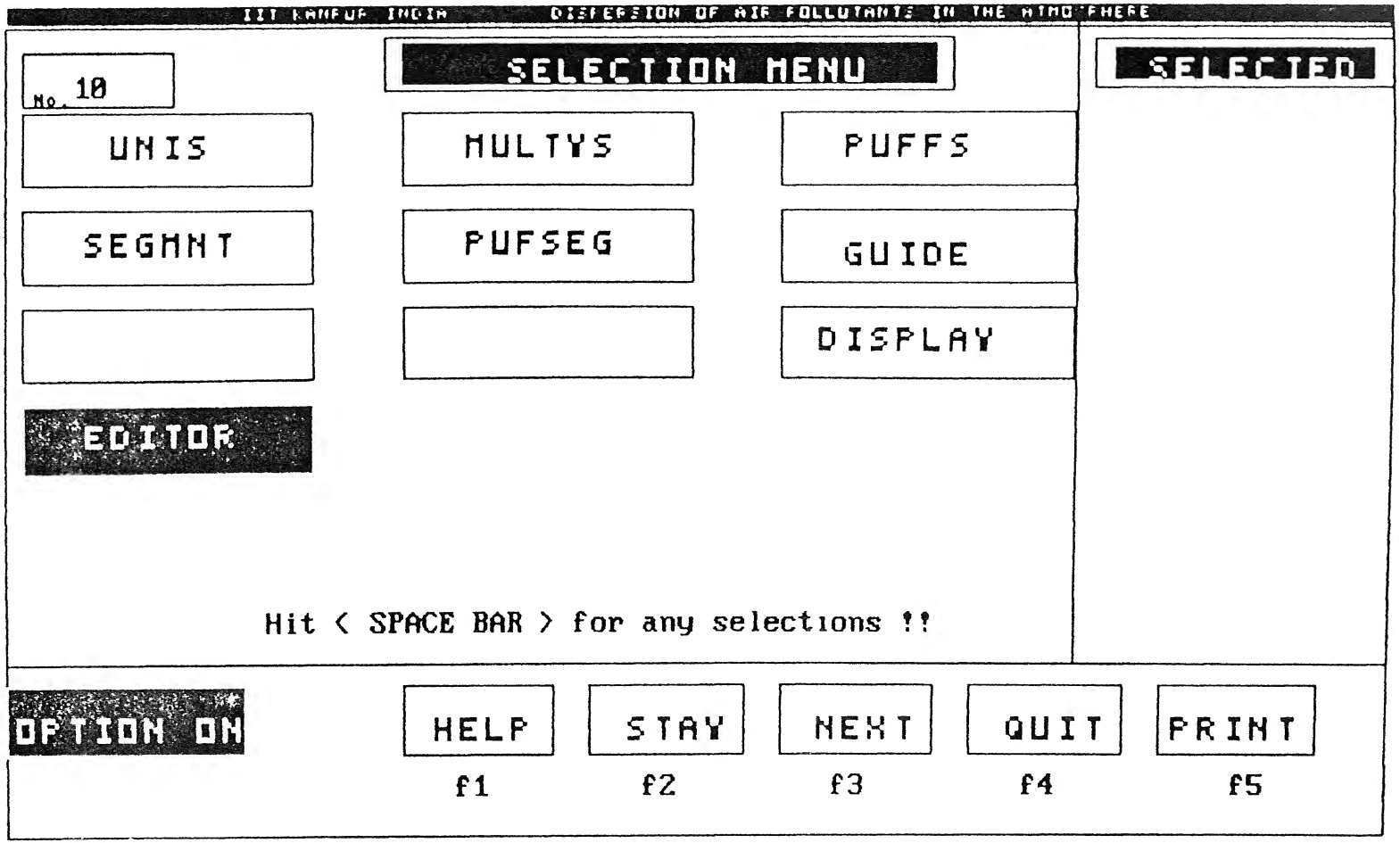


Fig 7.8 Screen display of SELECTION MENU with cursor on EDITOR option

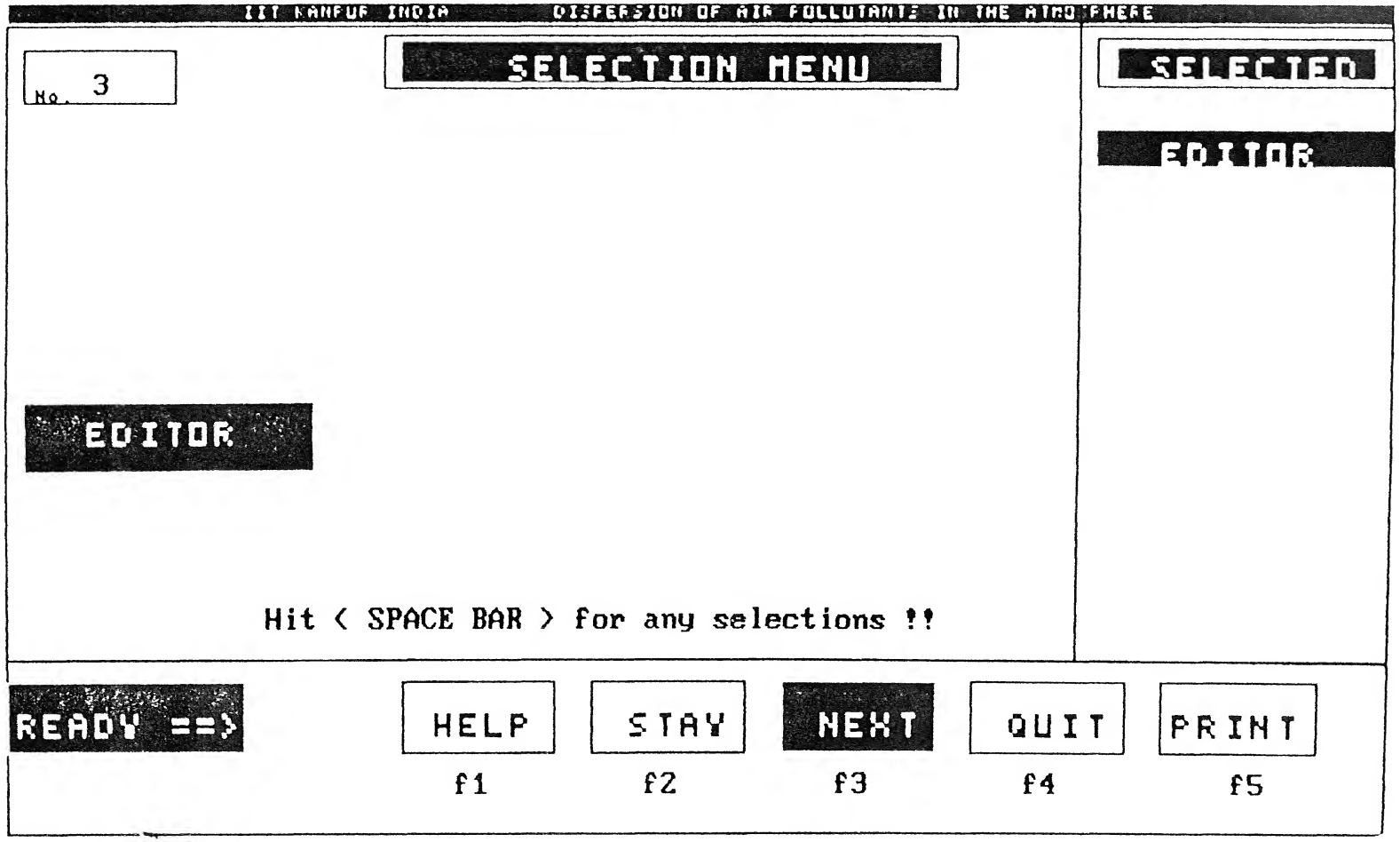


Fig. 7.9 Screen display after selecting EDITOR option

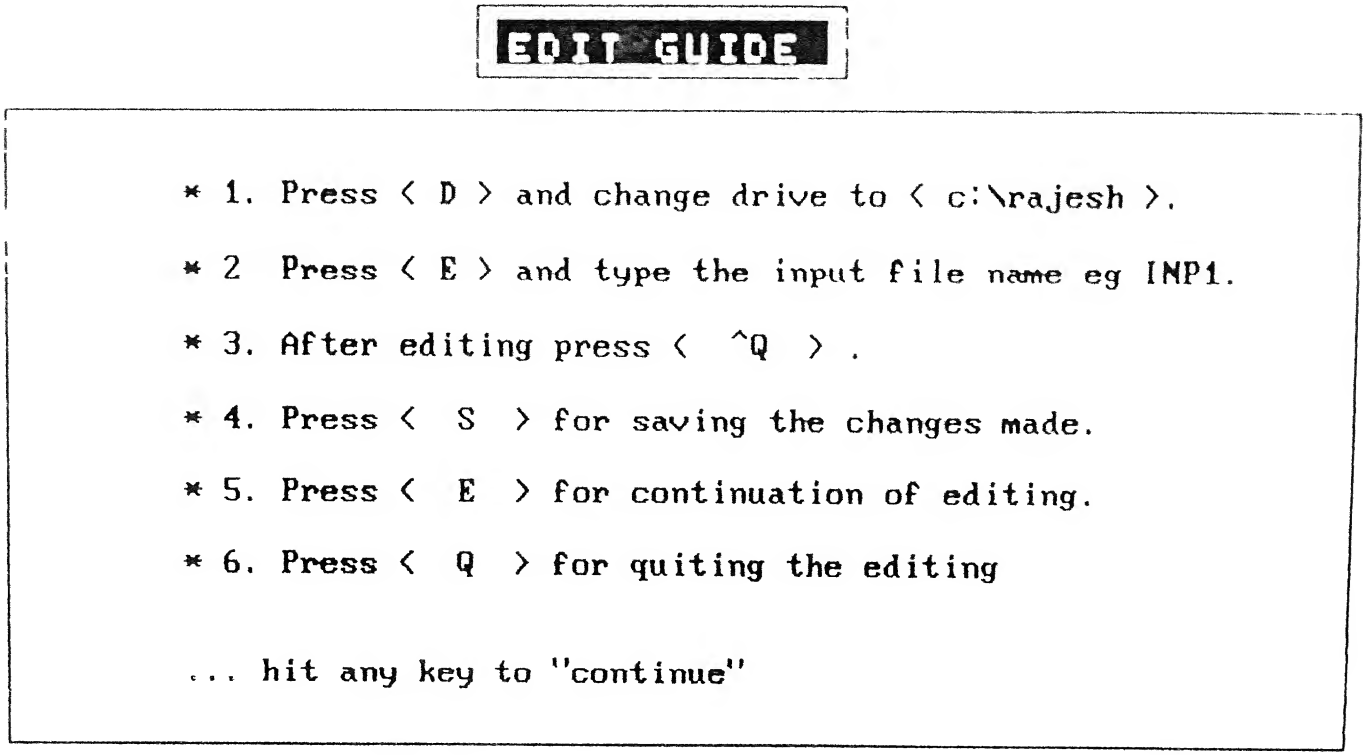


Fig. 7.10 Screen display of EDIT GUIDE

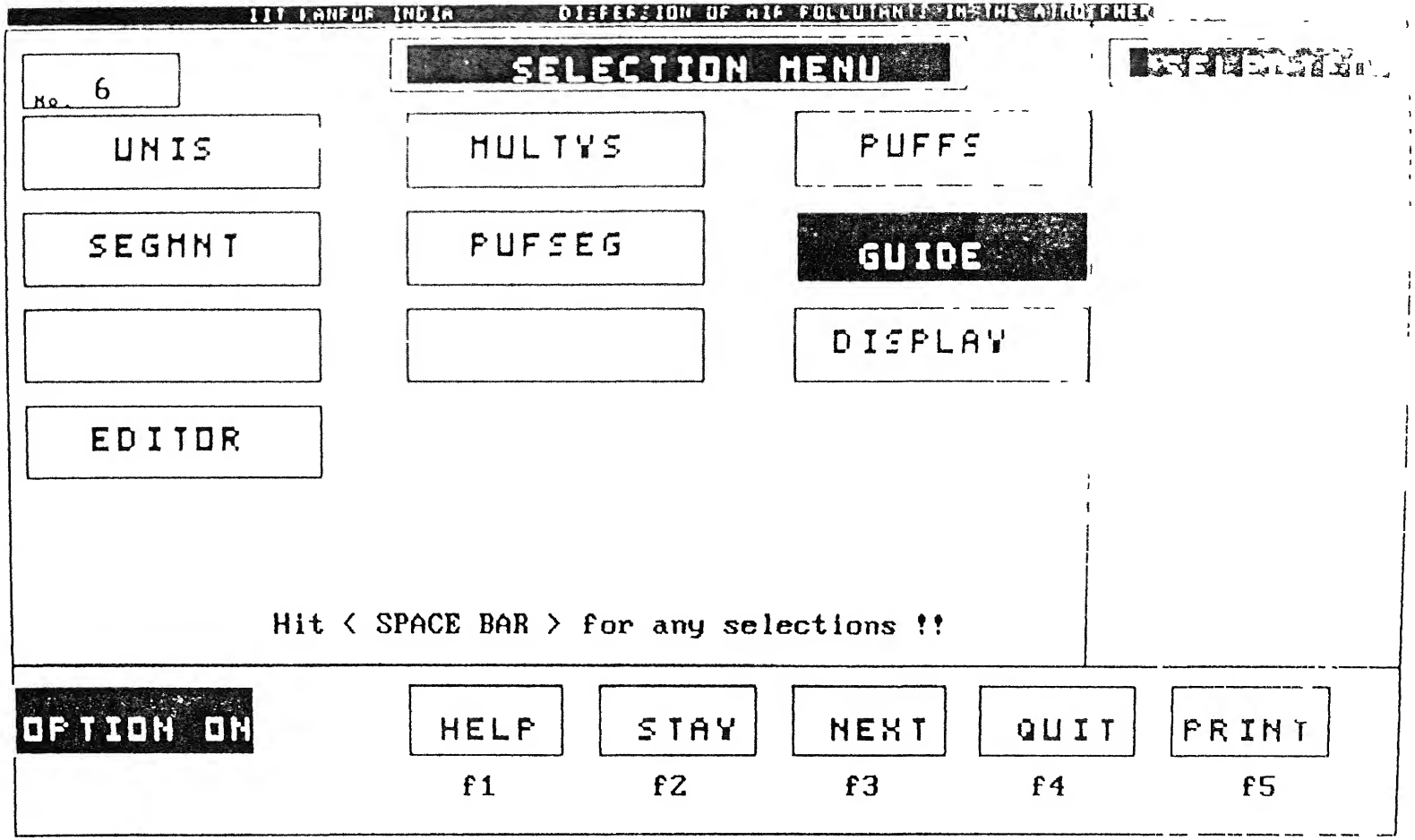


Fig. 7.11 Screen display of SELECTION MENU with cursor on GUIDE option

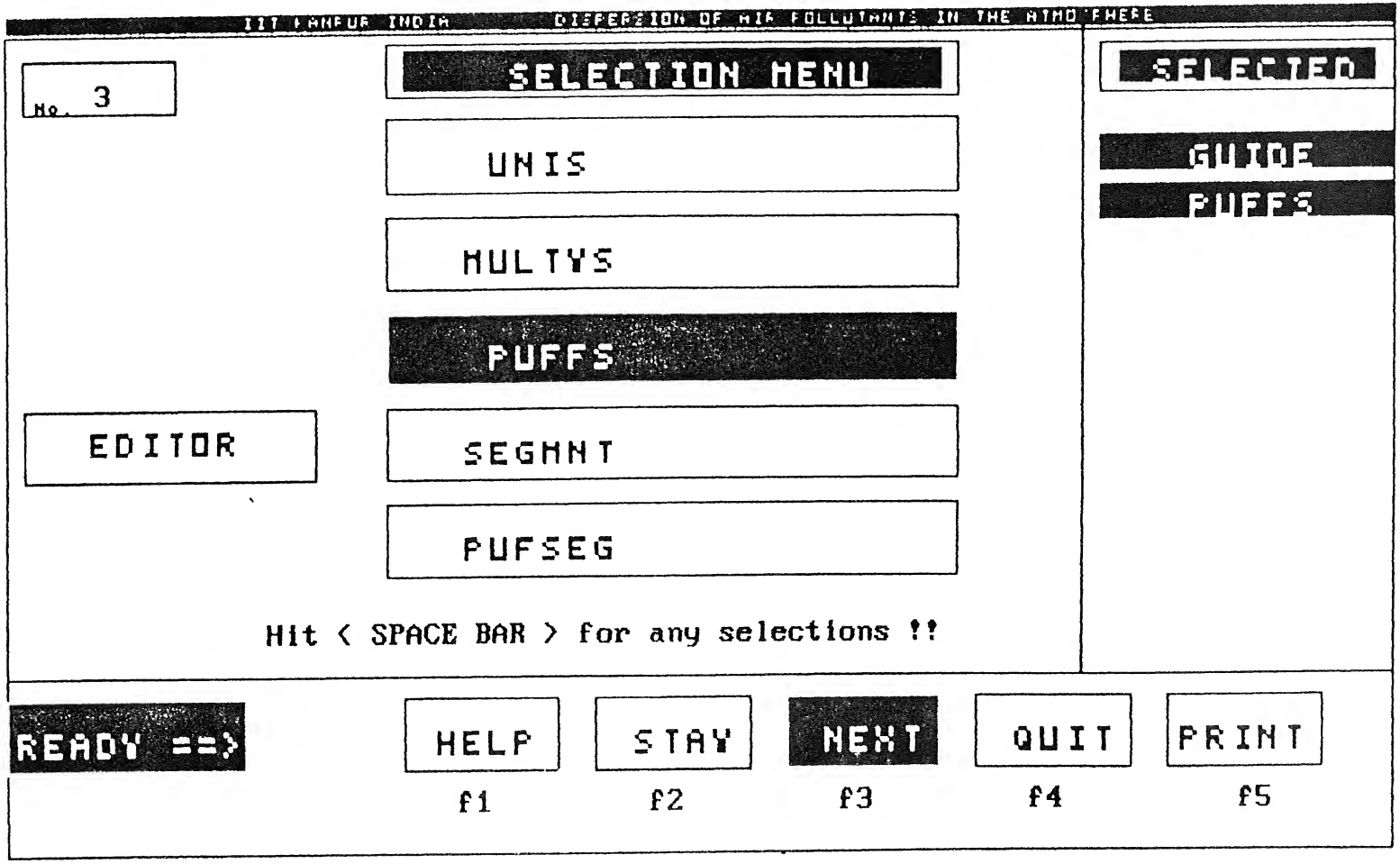


Fig. 7.12 Screen display of GUIDE sub options

```
. . .  .  . . .     << CAPABILITIES OF UNIS >>          . .  . . . . . .

   This option is built with the main objective to predict
   downwind, crosswind and vertical concentration profiles
   in stationary and homogeneous atmosphere using Gaussian
   model for a pollutant continuously released either from
   ground or an elevated point source at constant emission
   rate  Input to this option can be through file "INP1"
   or terminal  Digital output can be stored in a file to
   be specified when asked for

                  Press <ENTER> to continue

. . .  . . . . .  << CAPABILITIES OF UNIS >>          .  .        . . .

  SAMPLE INPUT

   2 00  11.00 1 00
   wind velocity(m/sec), at a height of(m), lapse rate(C/100m)

   1
   day (day=1, means it is day; day=2, means it is night)
   2
   solar radiation is moderate (1 means strong, 3 means mild)

   1 6e+08 120 00  15 00  80 00   0 75
   source characteristics:
   mass emission rate(microgm/sec ), heat emission rate(kj/sec.), gas exit
   velocity(m/sec ), dia  of the exit(m)

   0 50
   fractional reflection from the surface

   2 0    1 0    1 0
   Maximum, minimum and interval of downwind distances(all in km)
                                        Press <ENTER> to continue
```

Fig. 7.13 Screen display of guidelines for UNIS

```
                    << CAPABILITIES OF MULTYS >>          . .

 This option is built with the main objective to predict
 pollutant concentrations at selected locations ( called
 receptors) in a stationary and homogeneous atmosphere using
 Gaussian model for a pollutant continuously released from
 ground or an elevated point source at constant emission
 rate  Input to this option can be through file "INP2"
 or terminal  Digital output can be stored in a file to
 be specified when asked for
Sample INPUT
1  1
No  of receptor(s), no  of source(s)
                                          Press <ENTER> to continue

          .       << CAPABILITIES OF MULTYS >>      .   . . .

 12.00  35 00  50 00
 receptor coordinates (km,m,m)
 2 00  11.00 1 00
 wind velocity(m/sec), height(m), lapse rate(C/100m)

 1
 day (day=1, means it is day; day=2, means it is night)
 2
 solar radiation is moderate,(1 means strong, 3 means mild)

 0 00   0.00   0 00
 source coordinates (km,m,m)
 1 6e+08 120 00  15.00  80 00   0.75
 source characteristics:
 mass emission rate(microgm/sec ), heat emission rate(kj/sec.), gas exit
 velocity(m/sec.), dia  of the exit(m)

 0 50
 fractional reflection from the surface

                                          Press <ENTER> to continue
```

Fig 7.14 Screen display of guidelines for MULTYS

. .. .<< CAPABILITIES FOR PUFFS >>. . . . .

This option is built with the main objective to predict time dependent point concentrations of pollutant released from fluctuating (non-steady), ground or elevated source at selected locations (receptors) in non-stationary and inhomogeneous conditions This option should be selected if wind velocity is low i e calmwind conditions (wind velocity should be <= 1 m/sec). Some salient features of this option are as follows:
1.Entire region of source influence is divided into meteorological grid and each block of the grid is allowed to take different meteorological parameters after every meteorological time step specified by you.
2.Concentration computations are carried out at the interval specified by you
3.The plume profile specifies puff number, puff centre point coordinates, dispersion standard deviation and puff mass at a given time
4 Delay time in getting the results directly depends on number of puffs generated, number of receptors and time interval at which concentration values are required So CAREFULLY SELECT these values
5.INPUT to this option has to be through a file INP3 Output is in the digital form and can be stored in a file specified by you when asked for

Hit <ENTER> to continue

. .. . << CAPABILITIES FOR PUFFS >> . . . .

However, you would soon get next version of the package which will allow you to draw isoconcentration lines
6 Algorithm of this option is based on references Nema,A and Tare,V (1988) Computer Software for Atmospheric Dispersion of Pollutant", presented at the ENVIROSOFT 88-2nd International Conference on Computer Techniques in Environmental Studies Porto Carras, Greece, September 1988 and Zannetti, P (1986) "New Mixed Segment-Puff Approach for Dispersion Modelling", Atmospheric Environment, Vol 20, pp 1121-1130.

Hit <ENTER> to continue

Fig. 7.15(a) Screen display of guidelines for PUFFS -

```
. .     . ... .  . << CAPABILITIES FOR PUFFS >>.     . ..... . . . .. .

7               <SAMPLE INPUT>
50000 50000 15000 30000
Grid and block size(all in m) XMAX,DELX,YMAX,DELY

60 60 12 30
Time variables(all in min )
Max time,meteorological,element generation, and caculation time steps

1 5 10 90 0 0
Wind velocity(m/sec), height(m), angle of velocity vectors from Z and X axes

1 50 0 0 0 0 200
Lapse rate(C/100m), precipitation rate(mm/hr), settling velocity(m/sec),

1 1
Day(if 2 then it is night), strong solar radiation(2,3 meanmoderate and mild

1
Dry deposition(if 2 then it is wet deposition)
                                                    Hit <ENTER> to continue


 .   .     . . .     << CAPABILITIES FOR PUFFS >>          .   . .   .


 0 0 1
Scavenging ratio, rate constant(/hr), minimum wind velocity(m/sec)
15 120
Gas exit velocity(m/sec), heat emission rate(kj/sec)

1.6e+08 1.5e+08 1.4e+08 1.3e+08 1 5e+08
Mass emission rates(micro gm/sec)

0.75 100  0.5
Dia  of exit(m), stack height(m) and fraction reflection from ground

1
Number of receptor(s)

500 0 0
Receptor coordinates(all in m)


                                                    Hit <ENTER> to continue
```

Fig 7 15(b) Screen display of guidelines for PUFFS -

. . . . . << CAPABILITIES OF SEGMNT >> . . . . .

This option is built with the main objective to predict time dependent point concentrations of pollutant released from fluctuating (non-steady), ground or elevated source at selected locations (receptors) in non-stationary and inhomogeneous conditions This option should be selected for segmented plume i e transport conditions (wind velocity should be > 2-3 m/sec). Some salient features of this option are as follows
1 Entire region of source influence is divided into meteorological grid and each block of the grid is allowed to take different meteorological parameters after every meteorological time step specified by you
2 Concentration computations are carried out at the interval specified by you
3 The plume profile specifies puff number, puff centre point coordinates, dispersion standard deviation and puff mass at a given time
4 Delay time in getting the results directly depends on number of puffs generated, number of receptors and time interval at which concentration values are required So CAREFULLY SELECT these values
5 INPUT to this option has to be through a file INP3 Output is in the digital form and can be stored in a file specified by you when asked for

Hit <ENTER> to continue

. . . . . << CAPABILITIES OF SEGMNT >> . . . . .

However, you would soon get next version of the package which will allow you to draw isoconcentration lines
6 Algorithm of this option is based on references Nema,A and Tare,V (1988) Computer Software for Atmospheric Dispersion of Pollutant", presented at the ENVIROSOFT 88-2nd International Conference on Computer Techniques in Environmental Studies Porto Carras, Greece, September 1988 and Zannetti, P (1986) "New Mixed Segment-Puff Approach for Dispersion Modelling", Atmospheric Environment, Vol 20, pp 1121-1130

Hit <ENTER> to continue

Fig 7.16(a) Screen display of guidelines for SEGMNT -

```
. . . . .     . . .   << CAPABILITIES OF SEGMNT >>                    . .

7.              <SAMPLE INPUT>
50000 50000 15000 30000
Grid and block size(all in m) XMAX,DELX,YMAX,DELY

60 60 12 30
Time variables(all in min.)
Max time,meteorological,element generation, and caculation time steps

1 5 10 90 0 0
Wind velocity(m/sec),height(m),angle of velocity vectors from Z and X axes

1 50 0.0 0 0 200
Lapse rate(C/100m), precipitation rate(mm/hr), settling velocity(m/sec),

2 1
Night(if 1 then day), sky is clear(if 2 means covered with cloud

1
Dry deposition(if 2 then wet deposition)
                                                  Hit <ENTER> to continue
```

```
      . .             << CAPABILITIES OF SEGMNT >>                .     .   .


 0 0 1
Scavenging ratio, rate constant(/hr), minimum wind velocity(m/sec)
15 120
Gas exit velocity(m/sec), heat emission rate(kj/sec)

1 6e+08 1 5e+08 1.4e+08 1.3e+08 1.5e+08
Mass emission rates(micro gm/sec)

0 75 100  0 5
Dia  of exit(m), stack height(m) and fraction reflection from ground

1
Number of receptor(s)

500 0 0
Receptor coordinates(all in m)

                                                  Hit <ENTER> to continue
```

Fig. 7.16(b) Screen display of guidelines for SEGMNT -

<< CAPABILITIES OF PUFSEG >>

This option is built with the main objective to predict time dependent point concentrations of pollutant released from fluctuating (non-steady), ground or elevated source at selected locations (receptors) in non-stationary and in-homogeneous conditions This option should be selected for moderate meteorological conditions ie light wind conditions (wind velocity = 1-2 m/sec) Some salient features of this option are as follows:
1 Entire region of source influence is divided into meteorological grid and each block of the grid is allowed to take different meteorological parameters after every meteorological time step specified by you
2 Concentration computations are carried out at the interval specified by you
3 The plume profile specifies puff number, puff centre point coordinates, dispersion standard deviation and puff mass at a given time
4 Delay time in getting the results directly depends on number of puffs generated, number of receptors and time interval at which concentration values are required So CAREFULLY SELECT these values
5 INPUT to this option has to be through a file INP3 Output is in the digital form and can be stored in a file specified by you when asked for

Hit <ENTER> to continue

<< CAPABILITIES OF PUFSEG >>

However, you would soon get next version of the package which will allow you to draw isoconcentration lines
6 Algorithm of this option is based on references Nema,A and Tare,V.(1988) Computer Software for Atmospheric Dispersion of Pollutant", presented at the ENVIROSOFT 88-2nd International Conference on Computer Techniques in Environmental Studies Porto Carras, Greece, September 1988 and Zannetti, P. (1986) "New Mixed Segment-Puff Approach for Dispersion Modelling", Atmospheric Environment, Vol.20, pp 1121-1130

Hit <ENTER> to continue

Fig. 7.17(a) Screen display of guidelines for PUFSEG -

```
                    << CAPABILITIES OF PUFSEG >>

7                  <SAMPLE INPUT>
50000 50000 15000 30000
Grid and block size(all in m) XMAX,DELX,YMAX,DELY

60 60 12 30
Time variables(all in min )
Max time,meteorological,element generation, and caculation time steps

1 5 10 90 0 0
Wind velocity(m/sec),height(m),angle of velocity vectors from Z and X axes

1 50 0 0 0.0 200
Lapse rate(C/100m), precipitation rate(mm/hr), settling velocity(m/sec),

1 1
Day(if 2 then night), strong solar radiation(2,3 mean moderate and mild)

1
Dry deposition(2 means wet deposition)
                                                  Hit <ENTER> to   ntinue


                    << CAPABILITIES OF PUFSEG >>


0 0 1
Scavenging ratio, rate constant(/hr)  minimum wind velocity(m/sec)
15 120
Gas exit velocity(m/sec), heat emission rate(kj/sec)

1.6e+08 1 5e+08 1 4e+08 1 3e+08 1 5e+08
Mass emission rates(micro gm/sec)

0.75 100  0 5
Dia  of exit(m), stack height(m) and fraction reflection from ground

1
Number of receptor(s)

500 0 0
Receptor coordinates(all in m)

                                                  Hit <ENTER> to continue
```

Fig 7.17(b) Screen display of guidelines for PUFSEG - 2

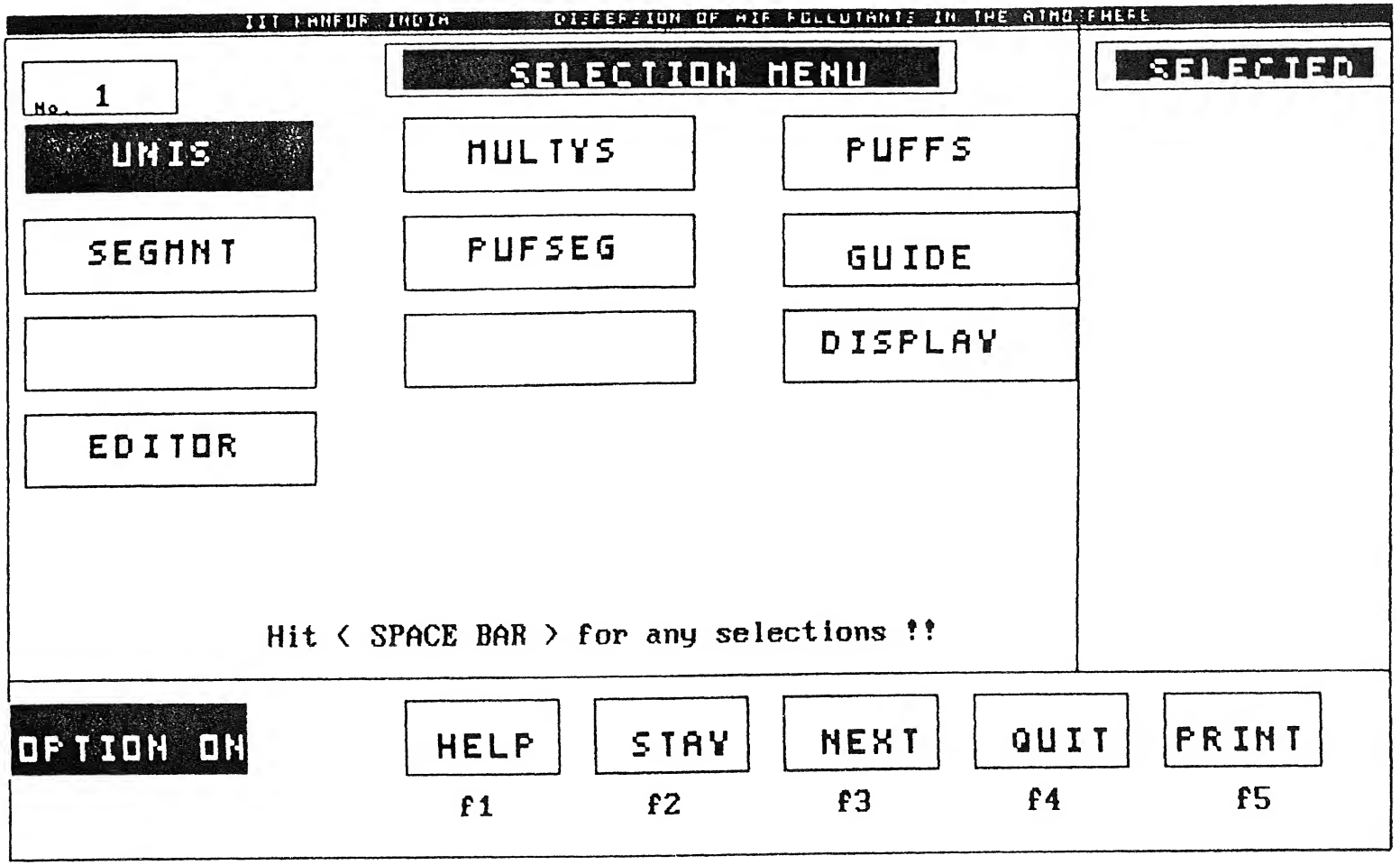


Fig. 7.18 Screen display of SELECTION MENU with cursor on UNIS option

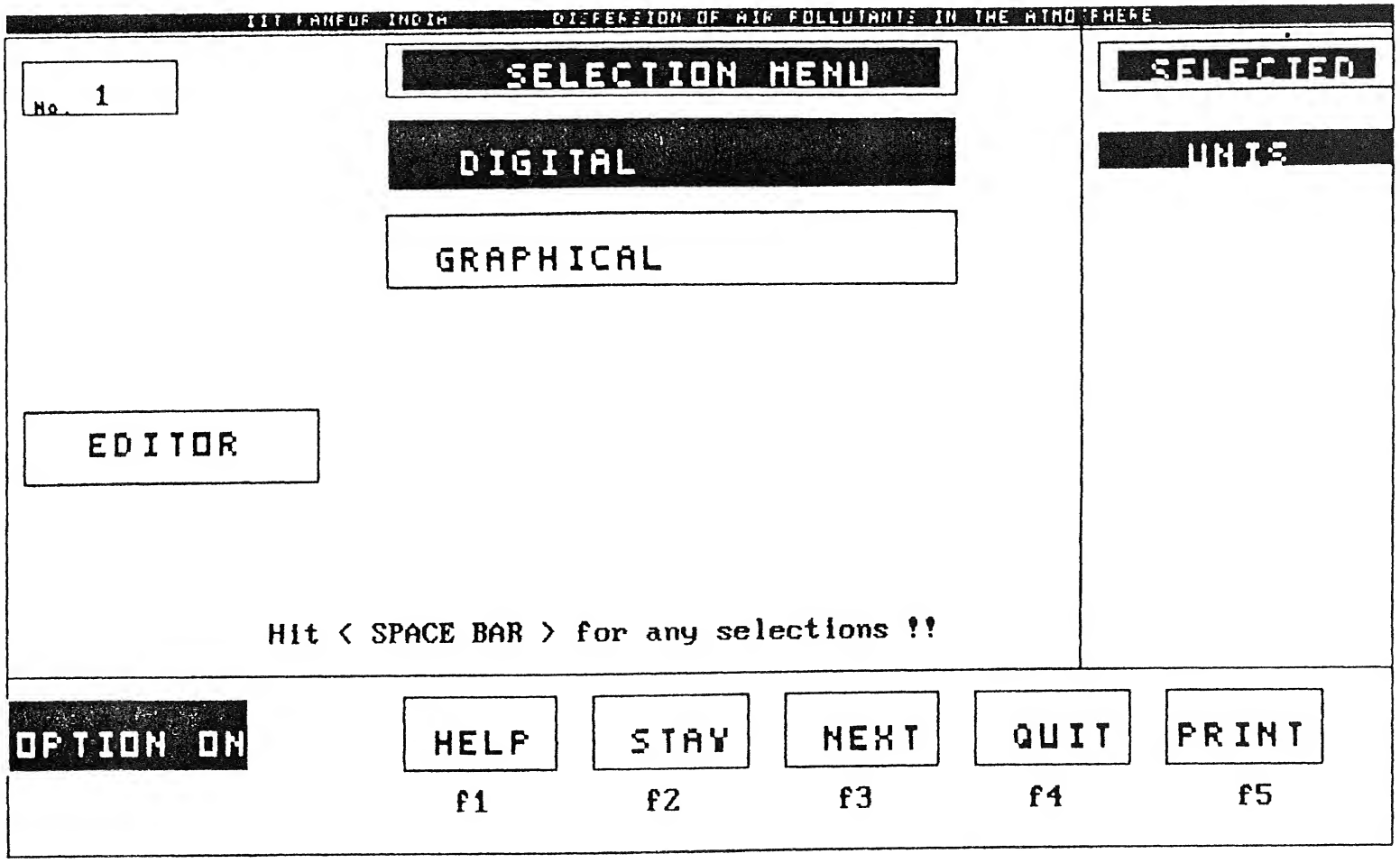


Fig. 7.19 Screen display of UNIS sub options

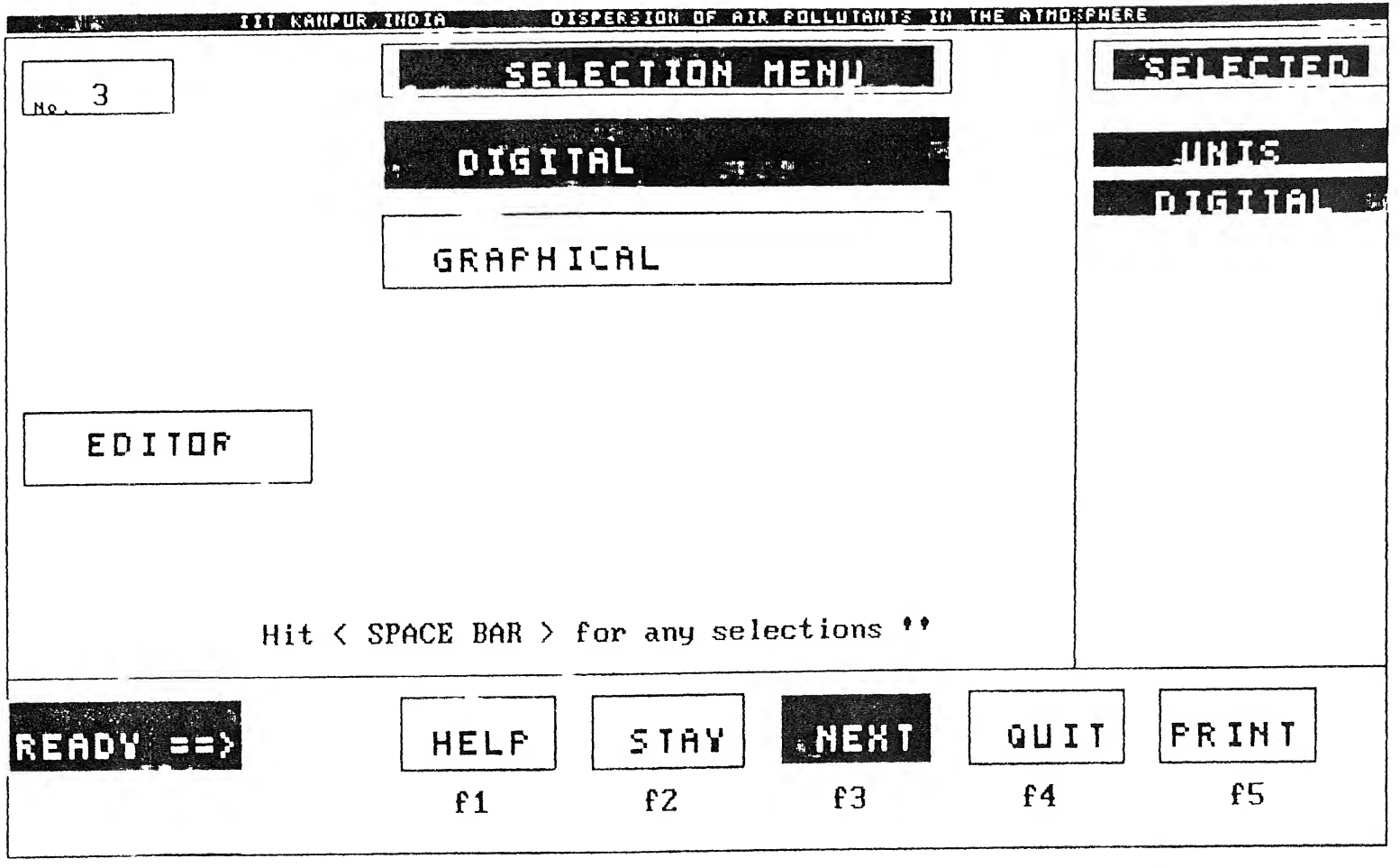


Fig. 7.20 Screen display of terminal selection in UNIS

...< TABLE 1: Key to Stability Classes >...

Wind Speed(m./sec.) at 10 m.ht.	DAY Incoming Solar Radiations			NIGHT Cloud Cover	
	Strong	Moderate	Slight	Mostly Overcast	Mostly Clear
< 2.0	A	A-B	B	E	F
2.0-3.0	A-B	B	C	E	F
3.0-5.0	B	B-C	C	D	E
5.0-6.0	C	C-D	D	D	D
>6.0	C	D	D	D	D

A: Most Unstable Class, B: Moderately Unstable Class, C: Slightly Unstable Class, D: Neutral Class, E: Slightly Stable Class, F: Most Stable Class

...< TABLE 2: Coefficients of SIGMA >...

STABILITY CLS.	Downwind distance(X) <= 1.0 km.				Downwind distance(X) > 1.0 km.		
	A	C	D	F	C	D	F
A	213.00	440.80	1.94	9.27	459.70	2.09	-9.60
B	156.00	106.60	1.15	3.30	108.20	1.10	2.00
C	104.00	61.00	0.91	0.00	61.00	0.91	0.00
D	68.00	33.20	0.73	-1.70	44.50	0.52	-13.00
E	50.50	22.80	0.68	-1.30	55.40	0.31	-34.00
F	34.00	14.35	0.74	-0.35	62.60	0.18	-48.60

Fig. 7.21 Screen display of (i) stability classification (Table 1) and (ii) dispersion standard deviation coefficients (Table 2)

<<.....UNIS --> Digital .....>>

concn. profile in y direction is

X(in km.)	Y(in m.)	Z(in m)	Concentration (microgm./cum)
1.000	0.000	156.887	138.826
1.000	91.418	156.887	126.611
1.000	182.836	156.887	96.044
1.000	274.254	156.887	60.600
1.000	365.673	156.887	31.803
1.000	457.091	156.887	13.883

this profile is at x= 1.000

Fig. 7.22 Screen display of digital output in UNIS - crosswind concentration profile

<<.....UNIS --> Digital .....>>

concn. profile in z direction is

X(in km.)	Y(in m.)	Z(in m.)	Concentration (microgm./cum)
1.000	0.000	156.887	138.826
1.000	0.000	125.510	140.432
1.000	0.000	94.132	141.436
1.000	0.000	62.755	141.828
1.000	0.000	31.377	141.603
1.000	0.000	0.000	140.766

this profile is at x= 1.000

Fig. 7.23 Screen display of digital output in UNIS - vertical concentration profile

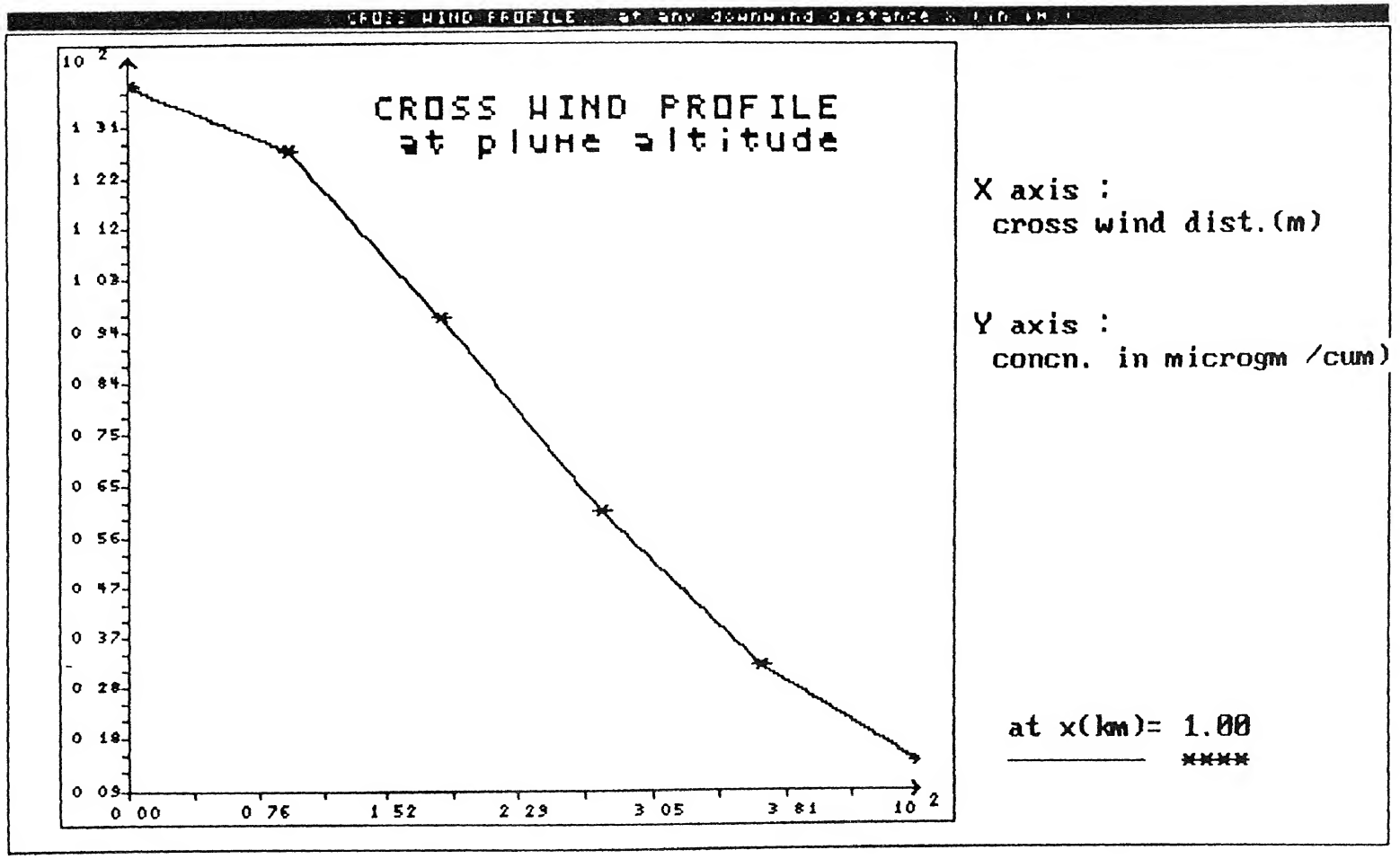


Fig. 7 24 Screen display of graphical output in UNIS - crosswind concentration profile

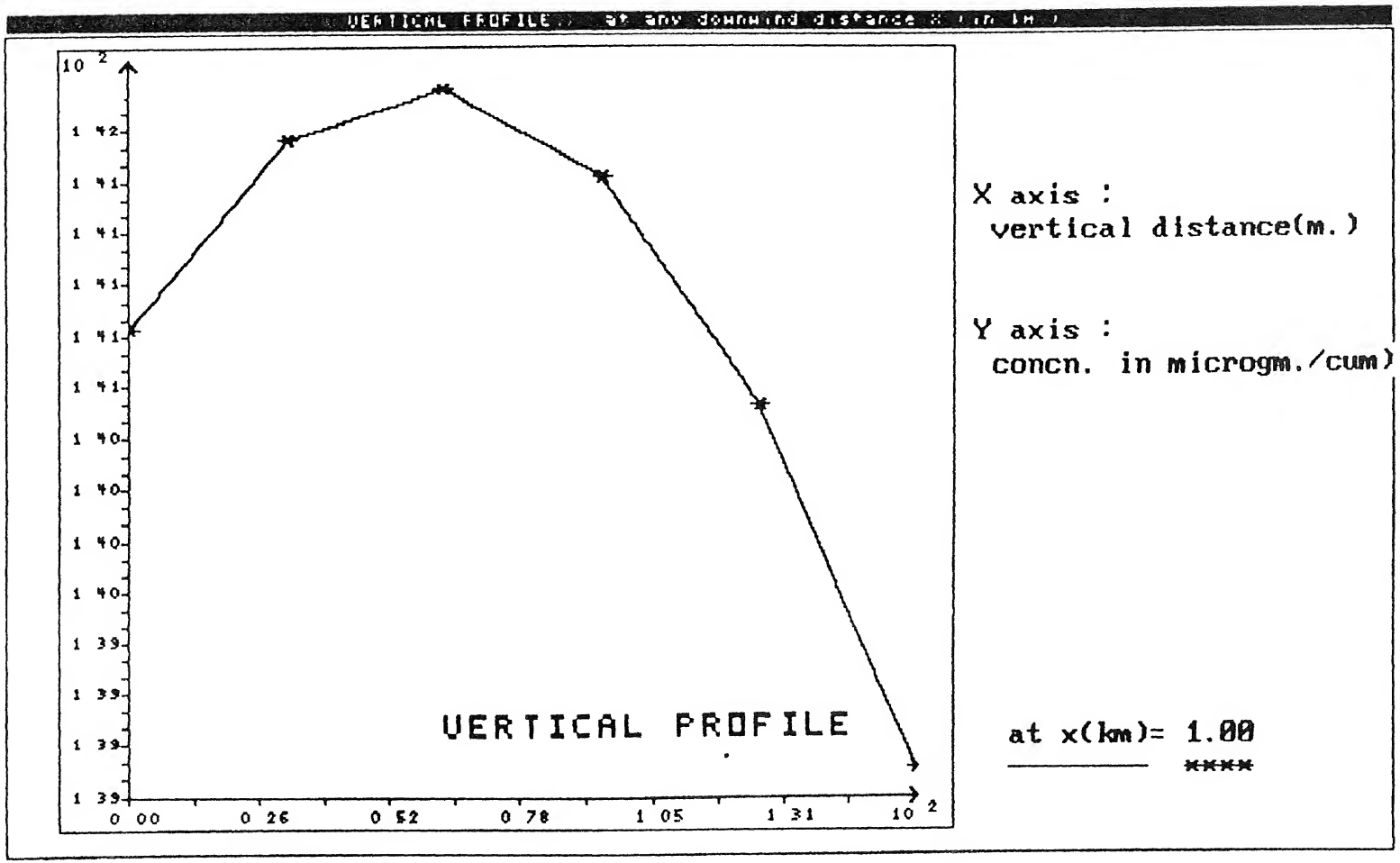


Fig. 7.25 Screen display of graphical output in UNIS - vertical concentration profile

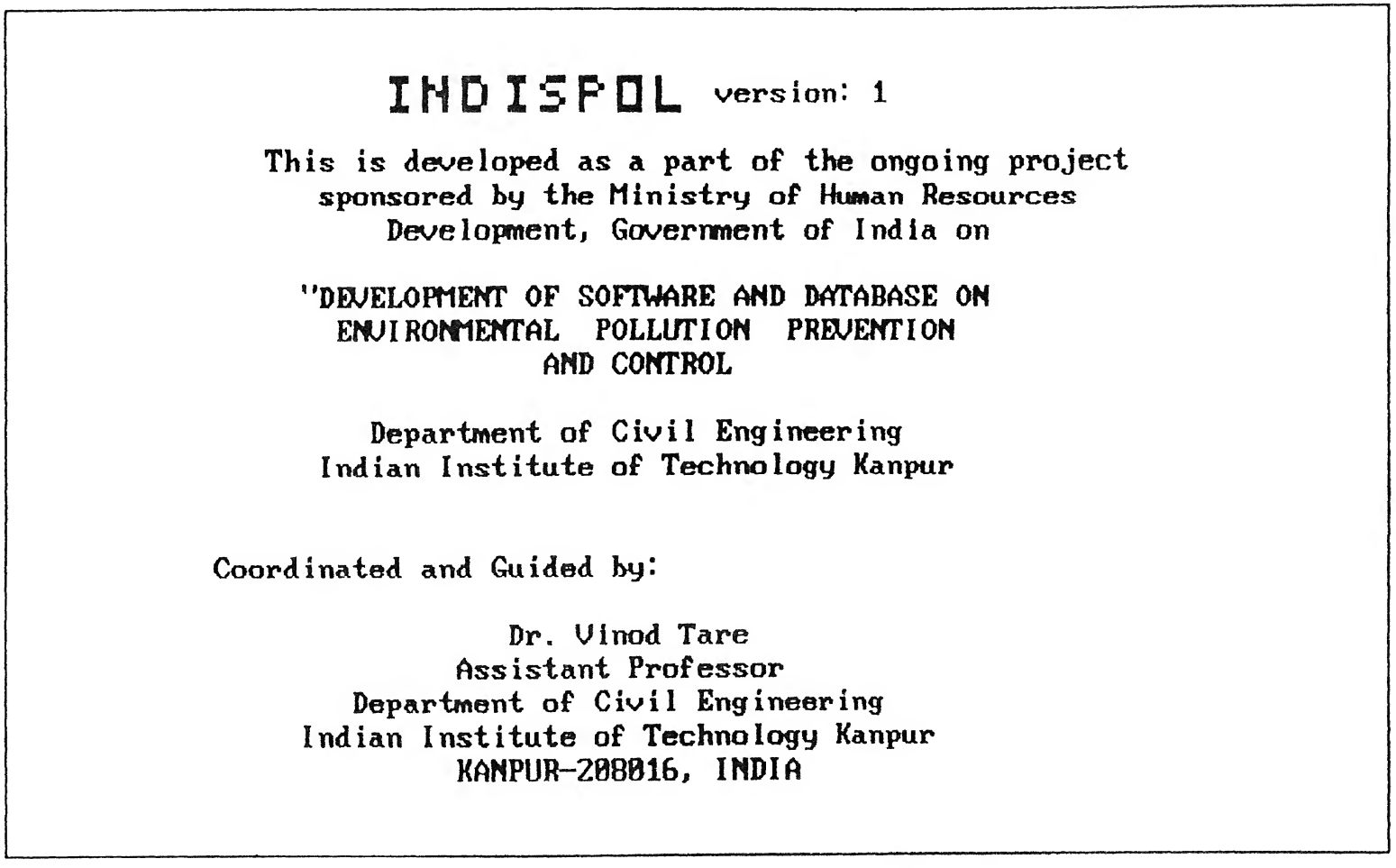


Fig. 7.26 Screen display of first end cover page

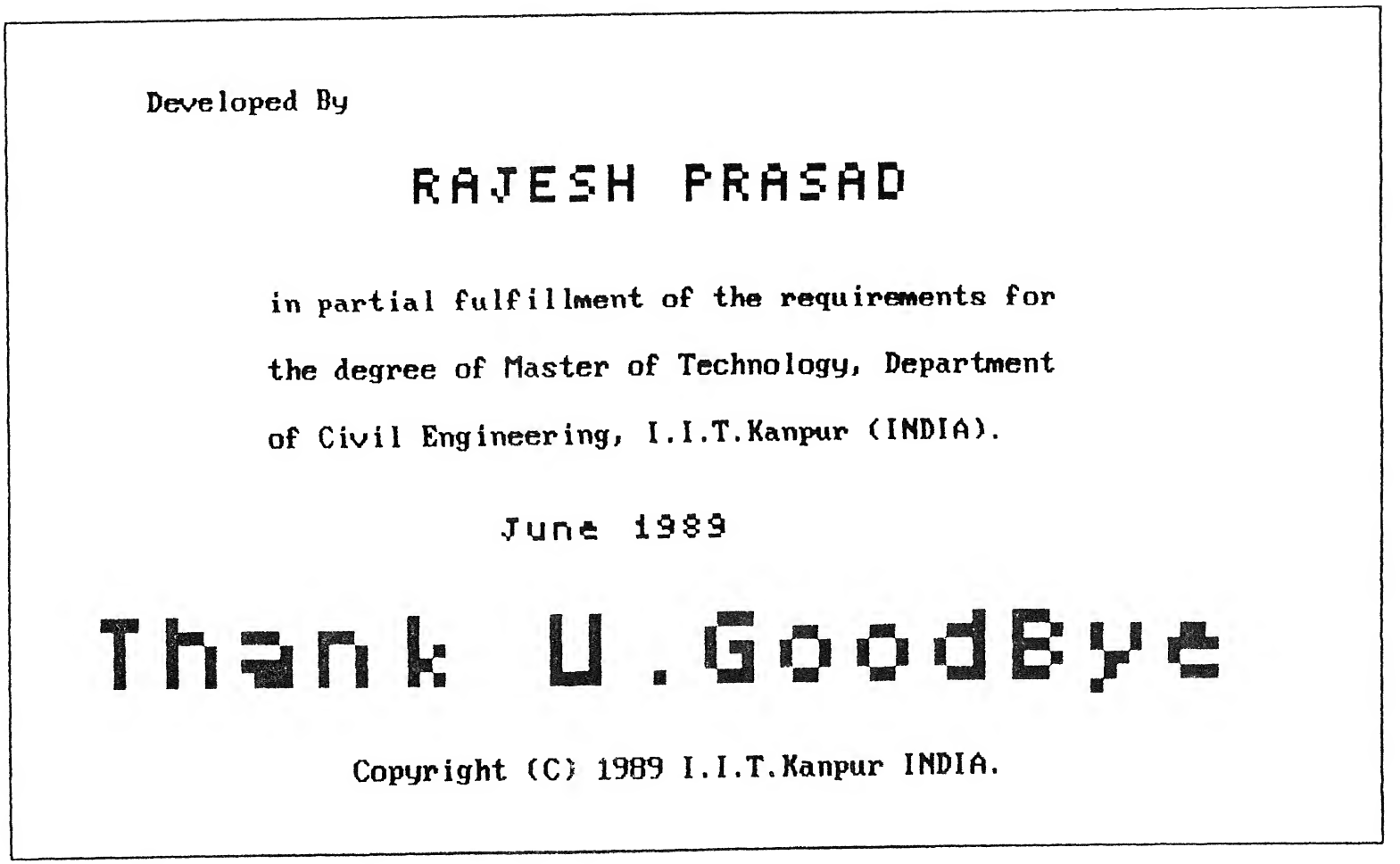


Fig. 7.27 Screen display of second end cover page

8 SUMMARY

Air pollutants which are emitted from industrial and other man-made sources affect the eco-system and its specific components, leading to harmful consequences It's, therefore, absolutely essential to study the dispersion of pollutants for the environmental assessment programme of polluted regions and to determine its impact on the environment For the estimation of pollutants' dispersion in the atmosphere several models are available To have simple and very useful solutions of complex atmospheric phenomena, computer aided simulation techniques are considered to be very useful The Interactive Packages provide extra simplicity in its use to the user In the present study efforts were made to develope a PC based Interactive Package to simulate pollutants' dispersion from continuous or short-term, steady or unsteady, surface or elevated sources in stationary or non-stationary, homogeneous or inhomogeneous atmosphere using basic Gaussian theory The package consists of a set of several programmes which are executed through a batch control file in MS DOS environment using TURBO PASCAL version 4 0 The problems for dispersion of pollutants are classified into five categories, UNIS for single, steady, and continuous source; MULTYS for steady and multiple continuous sources, and PUFFS, SEGMNT and PUFSEG for calmwind, transport and lightwind conditions considering transformation and transportation of pollutants respectively Depending upon stack characteristics, meteorological conditions and the physico-chemical nature of the effluent, plume rise and hence effective stack height is calculated The power law is used for wind velocity profile in which power depends upon the lapse-rate Dispersion standard deviations are determined by the mixing or dispersive power of the turbulent flow within the planetary boundary layer UNIS provides the crosswind and vertical profile of the pollutants assuming homogeneous and stationary atmosphere in the given domain in tabular and graphical forms MULTYS is extended form of UNIS in which there are multiple sources The principle of linear superposition is used to

calculate the concentration at any required receptor locations due to several sources neglecting the interference between any two PUFFS, SEGMNT and PUFSEG simulate pollutants' dispersion from short term or continuous, steady or fluctuating emissions in non stationary and inhomogeneous atmosphere The non-stationary conditions in meteorology and emissions are treated as the point source emission into the atmosphere by a series of instantaneous puffs/segments/elements whose characteristics are updated at each dispersion time interval Meteorological three dimensional fields and emission parameters are also updated at each meteorological time step For the dynamics of a puff/segment/element, following things are considered - its generation at the source, plume rise, transportation by advective wind, diffusion by atmospheric turbulance, ground deposition which could be dry or wet, and its chemical transformation From the main MENU, which is specially designed for this package, the user can go into any of the five mentioned categories of the problems The package provides on-line help, guide and editing facilities which are self explanatory

The package developed may prove to be a valuable tool for estimating the extent of air pollution and decision making for local and regional development However, there is a need to refine/modify/extend the package structure/scope to enhance its applications Following are a few suggestions on these lines

1 The options which are not supported presently, but are available in the current INDISPOL structure, should be fully implemented For example, the CONTOUR option can easily be developed by making provisions for having access to available package to draw contours (isoconcentration lines) on a similar logic that is used for providing editing facilities by giving access to WORDSTAR 2000

2 The computational procedure used in PUFFS, SEGMNT and PUFSEG can be made more efficient by choosing varying puff/ segment/element generation/advection time depending upon the calculation time and receptor locations

3 The simulation procedures themselves should be modified (i) to give statistical computations such as time average concentration and standard deviation in concentrations, (ii) to include effect of upper layer inversion, concentration computation of secondary pollutants, variation in chemical reaction rate constant etc, and (iii) to consider abrupt changes in the meteorological conditions

REFERENCES

Benarie, M M (1987) "Editorial: The limits of air pollution modelling", *Atmospheric Environment*, Vol 21, pp 1-5

Benkley, C W and Bass, A (1980) Development of Mesoscale Air Quality Simulation Models, Vol 3 User's Guide to MESOPUFF (Mesoscale Puff) Model, EPA 600/7-80-058 Cited in Zannetti (1986)

Bowne, N E (1974) "Diffusion rates", *J Air Polln Cont Assoc*, Vol 24, pp 832-835

Carson, J E and Moses, H (1969) "The validity of several Plume rise formulas", *J Air Polln Cont Assoc*, Vol 19, pp 862-866

Chen, M W, Head, S J and Machiraju, S (1979) "Development and validation of an air pollution model for complex terrain application", Paper presented at NATO/CCMS Air Pollution Pilot Study, Rome, Italy Cited in Zannetti (1986)

Dobbins, R A (1979) Atmospheric Motion and Air Pollution, John Wiley & Sons, New York, U S A

Enger, L (1986) "A higher order closure model applied to dispersion in a convective PBL", *Atmospheric Environment*, Vol 20, pp 879-894

Frenkiel, F N and Goodall, D W (1978) Simulation Modelling of Environmental Problems, Wiley and Sons, New York, U S A

Hales, J,M, Powell, D C and Fox, T D (1977) STRAM - an Air Pollution Model Incorporating Nonlinear Chemistry, Variable Trajectories, and Plume Segment Diffusion, EPA 450/3-77-012 Cited in Zannetti (1986)

Krogstad, P A and Patterson, R M (1986) "Windtunnel modelling of a release of a heavy gas near a building", *Atmospheric Environment*, Vol 20, pp 867-878

Lamb, R G (1984) "Air pollution models as descriptors of cause-effect relationships", *Atmospheric Environment*, Vol 18, pp 591-606

Lamb, R G and Neiburger, M (1971) "An interim version of a generalized urban diffusion model", *Atmospheric Environment*, Vol 5, pp 239-264

Ludwig, F.L., Gassiorek, L.S. and Ruff, R.E. (1977) "Simplification of a Gaussian puff model for real-time minicomputer use", *Atmospheric Environment*, Vol.11, pp 431-436.

Martin, D.O. (1976) "The change of concentration standard deviation with distance", *J. Air Polln. Cont. Assoc.*, Vol.26, pp 145-146.

Nema, A. (1987) Computer Aided Simulation of Air Pollutant Dispersion Under Non-Homogeneous and Unsteady conditions Adopting Segmented Plume Approach, M.Tech. Thesis, Department of Civil Engineering, IIT Kanpur. India.

Nema, A. and Tare, V. (1988) "Computer Software for Atmospheric Dispersion of Pollutant", presented at the ENVIROSOFT-2nd International Conference on Computer Techniques in Environmental Studies, Porto Carras, Greece, September 1988.

Nema, A. and Tare, V. (1989) "Atmospheric Dispersion of Pollutants under Non-homogeneous conditions", *Atmospheric Environment*, Vol. 23(4), pp 851-856.

Page, B. (1988) "Environmental Computing - Status and Research Perspectives". Proceedings ENVIROSOFT 88 - Computer Techniques in Environmental Studies, Computational Mechanics Publication, Southampton, U.K., pp 597-607.

Pasquill, F. (1974) Atmospheric Diffusion, 2nd Ed., Ellis Harwood, Chichester, U.K.

Popper, K. (1959) The Logic of Scientific Discovery, Basic Books, Inc., New York, NY, U.S.A.

Robins, A.G. and Fackrell, J.E. (1979) "Continuous plumes - their structure and prediction", in Mathematical Modelling of Turbulent Diffusion in the Environment, Ed. Harris, C.J., Academic Press, London, pp 55-114.

Sheih, C.M. (1978) "A puff pollutant dispersion model with wind shear and dynamic plume rise", *Atmospheric Environment*, Vol. 12, pp 1933-1938.

Shukla, J.B. and Chauhan, R.S. (1986) "Atmospheric dispersion model of removal mechanism with integral term", *Appl. Maths. Modelling*, Vol. 11, pp 82-88.

Stern, A.C. (1968) Air Pollution Vol.I, Academic Press, New York. U.S.A.

Swadas, B.P. (1974) Langrargian Similarity Theory Applied to Diffusion in Surface Layer of the Atmosphere, Ph.D. Thesis, Department of Civil Engineering, Indian Institute of Technology Kanpur, India.

Tadmor, J and Gur, Y (1969) "Analytical expressions for the vertical and lateral dispersion coefficients in atmospheric diffusion", *Atmospheric Environment*, Vol 3, pp 688-689

Turner, D B (1969) Workbook of Atmospheric Dispersion Estimates, Hew, Washington, D C, U S A

van Stijn, T L and Nieuwstadt, F T M (1986) "On the relation between a Lagrangian and a Eulerian model of diffusion in homogeneous, stationary and non-Gaussian turbulence", *Atmospheric Environment*, Vol 20, pp 1111-1120

Wark, K and Warner, C F (1981) Air Pollution: Its Origin and Control, 2nd Ed, Harper & Row, Publishers, New York, U S A

Zannetti, P. (1981) "An improved puff algorithm for plume dispersion simulation", *J Appl Met*, Vol 20, pp 1203-1211

Zannetti, P (1984) "New Monte Carlo sheme for simulating Lagrangian particle diffusion with wind shear effects", *Appl Math Modelling*, Vol 8, pp 188-192

Zannetti, P (1986) "New mixed segment-puff approach for dispersion modelling", *Atmospheric Environment*, Vol 20, pp 1121-1130

APPENDIX I LIST OF TURBO PASCAL FILES REQUIRED FOR INDISPOL EXECUTION

1 GDRIVER TPU

2 GKERNEL TPU

3 GSHELL TPU

4 GWINDOW TPU

5 14X9 FON

6 8X8 FON

7 4X6 FON

APPENDIX II INDISPOL BATCH FILE

```
echo off
path = c.\,c:\rajesh;c:\ws2000,
INTRODUC
PERMIT
If exist DUMY goto ter
INFO
 loop
del OPDUM
del GUIDE *
del DMLV *
MAINMENU
If exist dumy goto ter
RUNN
If not exist ALC 11 goto lvl1
DOL1
If exist DMLV11 goto lvl1
If not exist DMLV1 goto arbit1
EDIT
cd\ws2000
ws2
cd c:\rajesh
 arbit1
CALTABLE
cls
UNISDGTL
.lvl1
If not exist ALC 12 goto lvl2
DOL2
If exist DMLV12 goto lvl2
If not exist DMLV2 goto arbit2
EDIT
cd\ws2000
ws2
cd c:\rajesh
:arbit2
CALTABLE
cls
UNISGRF
:lvl2
If not exist ALC.21 goto lvl3
DOL3
If exist DMLV13 goto lvl3
If not exist DMLV3 goto arbit3
EDIT
cd\ws2000
ws2
cd c:\rajesh
:arbit3
CALTABLE
cls
RECPCONC
:lvl3
If exist ALC.22 CONTOUR
If not exist ALC.30 goto lvl4
DOL4
If exist DMLV14 goto lvl4
```

```
If not exist DMLV4 goto arbit4
EDIT
cd\ws2000
ws2
cd c:\rajesh
:arbit4
CALTABLE
cls
PUFFS
:lvl4
If not exist ALC.40 goto lvl5
DOL5
If exist DMLV15 goto lvl5
If not exist DMLV5 goto arbit5
EDIT
cd\ws2000
ws2
cd c\rajesh
.arbit5
CALTABLE
cls
SEGMNT
:lvl5
If not exist ALC.50 goto lvl6
DOL6
If exist DMLV16 goto arbit6
If not exist DMLV6 goto arbit6
EDIT
cd\ws2000
ws2
cd c:\rajesh
:arbit6
CALTABLE
cls
PUFSEG
:lvl6
If exist GUIDE.61 GUID1
If exist GUIDE.62 GUID2
If exist GUIDE.63 GUID3
If exist GUIDE.64 GUID4
If exist GUIDE.65 GUID5
If exist GUIDE.* goto loop
del ALC.*
If not exist OPDUM goto notdon
DOLL
If not exist DUM1 goto notdon
EDIT
cd\ws2000
ws2
cd c\rajesh
:notdon
If exist OPDUM goto loop
CHECK
If exist DUM goto loop
LAST
:ter
```

APPENDIX III SAMPLE INPUT AND OUTPUT FILES OF UNIS

Sample Input File

```
2   11   1
1
1
1.7e+08   120   13   125   0.75
0.5
1.0    0.0    1.0
```

Sample Output File

concn. profile in y direction is

X(in km.)	Y(in m)	Z(in m.)	Concentration (microgm./cum)
1 000	0 000	156.887	138 826
1 000	91 418	156.887	126.611
1 000	182.836	156.887	96.044
1.000	274 254	156.887	60.600
1.000	365 673	156.887	31.803
1 000	457.091	156.887	13.883

concn profile in z direction is

1.000	0.000	156.887	138.826
1.000	0.000	125.510	140.432
1.000	0.000	94.132	141.436
1.000	0.000	62.755	141.828
1.000	0.000	31.377	141.603
1.000	0.000	0.000	140.766

APPENDIX IV SAMPLE INPUT AND OUTPUT FILES OF MULTYS

Sample Input File

```
10   5
0 50      0 00     0 000
0 75      0 00     0 000
1 00      0 00     0 000
1 00     50 00     0 000
1 00    -50 00     0 000
1 00      0 00    35 000
1 00      0 00    75 000
1 25      0 00     0 000
1 50      0 00     0 000
3 00      0 00     0 000
2 50     10 00   1 50
1
1
0 00      0 00      0 00
160000000 00   120 00    15 00    100 00      0 75
0 25     50 00      0 00
100000000 00    80 00    12 00    100 00      0 50
0 25    -50 00      0 00
100000000 00    85 00    20 00     75 00      0.50
0 50      0 00      0 00
100000000 00    90 00    18 00     75 00      0 50
1 00      0 00      0 00
100000000 00    40 00    15 00     40 00      0 50
0 50
```

Sample Output File

```
    stability class: A which is most unstable
    ^^^^^^^^^ ^^^^^  ^ ^^^^^ ^^ ^^^^ ^^^^^^^^

-------------------------------------------------------
 no    source coordinates       eff ht        discharge
         x:km ,y:m ,zm             m          microgm /sec
 --   ---------------           ---          ------------
  1   0 00   0 00   0 00        129 56        1.6E+08
  2   0 25 50 00   0 00        120 71        1.0E+08
  3   0 25-50 00   0 00        101 28        1 0E+08
  4   0 50   0 00   0 00        100 61        1.0E+08
  5   1 00   0 00   0 00         60 09        1.0E+08
*******************************************************

     pollutant concn in desired receptors
     ^^^^^^^^^ ^^^^  ^^ ^^^^^^^ ^^^^^^^^^

    no    receptor position       concentration
            x:km ,y m ,z m        microgm /cu.m
    --   -----------------        -------------
     1   0.50    0 00    0 00       612 874
     2   0.75    0 00    0 00       1046.822
     3   1 00    0 00    0 00       838 248
     4   1 00   50 00    0 00       785 472
     5   1.00  -50 00    0 00       786 353
     6   1.00    0 00   35 00       866 287
     7   1.00    0 00   75 00       870 885
     8   1.25    0 00    0 00       1386.423
     9   1.50    0 00    0 00       687 670
    10   3 00    0 00    0 00        27 866
   ------------------------------------------------------
```

APPENDIX V SAMPLE INPUT AND OUTPUT FILES OF PUFFS, SEGMNT AND PUFSEG

Sample Input File of PUFFS, SEGMNT AND PUFSEG

```
50000 50000 15000 30000

60 60 2.5 30

0.8 10 90 0.0

1.50 0.0 0.0 200

1 1

1

0 0 1

15 120

1.6e+08 1 5e+08 1.4e+08 1.3e+08 1.5e+08 1.2e+08
1.5e+08 1 6e+08 1.5e+08 1.4e+08 1.7e+08 1.4e+08
1.6e+08 1.5e+08 1.4e+08 1.3e+08 1.5e+08 1.2e+08
1.5e+08 1.6e+08 1.5e+08 1.4e+08 1.7e+08 1.4e+08

0.75 100  0.5

10

500 0 0
1000 0 0
1000 +50 0
1000 -50 0
1000 0 50
1000 0 75
1500 0 0
2000 0 0
3500 0 0
4500 0 0
```

Sample Output File of PUFFS

Plume profile at 30 0 min.

Puff No	Centre point coordinates(km)			Puff Mass (gm)	Rectangle #		sigmay <----(m)----->	sigmaz	ISC Stb Cls
1	1.83	0 00	0 19	24000.00	1	1	366 21	1626.23	1
2	1.67	0.00	0 19	22500 00	1	1	336 30	1330.27	1
3	1 50	0 00	0 19	21000 00	1	1	306 07	1065 00	1
4	1 33	0 00	0 19	19500 00	1	1	275 48	830 12	1
5	1 17	0 00	0 19	22500 00	1	1	244 48	625 29	1
6	1.00	0 00	0 19	18000 00	1	1	213 01	450 14	1
7	0 83	0 00	0 19	22500.00	1	1	180 97	318.72	1
8	0 67	0 00	0 19	24000 00	1	1	148 24	209.94	1
9	0 50	0 00	0 19	22500 00	1	1	114 62	124.08	1
10	0 33	0 00	0 19	21000 00	1	1	79 77	61.53	1
11	0 17	0.00	0 19	25500 00	1	1	42 93	22.88	1
12	0.00	0.00	0 19	21000 00	1	1	0 28	29.23	1

Concentration profile at 30 0 min

1	CRecp coordinates:	500.00	0 00	0 00]	cr(microgm/cu m): 475.13
2	CRecp coordinates	1000 00	0.00	0 00]	cr(microgm/cu m): 279 70
3	CRecp coordinates:	1000 00	50.00	0 00]	cr(microgm/cu m): 270 76
4	CRecp coordinates	1000 00	-50.00	0 00]	cr(microgm/cu m): 270 76
5	CRecp coordinates:	1000 00	0.00	50 00]	cr(microgm/cu m): 285 16
6	CRecp coordinates:	1000 00	0.00	75 00]	cr(microgm/cu m): 286 58
7	CRecp coordinates:	1500 00	0.00	0 00]	cr(microgm/cu m): 89.63
8	CRecp coordinates	2000 00	0.00	0 00]	cr(microgm/cu m): 24 91
9	CRecp coordinates	3500 00	0.00	0 00]	cr(microgm/cu m): 0 00
10	CRecp coordinates:	4500 00	0.00	0 00]	cr(microgm/cu m): 0 00

Plume profile at 60 0 min

Puff No	Centre point coordinates(km)			Puff Mass (gm)	Rectangle #		sigmay <----(m)----->	sigmaz	ISC Stb Cls
1	3 83	0.00	0 19	24000.00	1	1	708 13	7655.55	1
2	3 67	0.00	0 19	22500 00	1	1	680 54	6974 26	1
3	3 50	0 00	0.19	21000 00	1	1	652 82	6326 03	1
4	3 33	0.00	0 19	19500 00	1	1	624 96	5710 70	1
5	3 17	0 00	0 19	22500 00	1	1	596 94	5128 14	1

6	3 00	0 00	0 19	18000 00	1	1	568 78	4578 18	1
7	2 83	0 00	0 19	22500 00	1	1	540 44	4060 66	1
8	2 67	0 00	0 19	24000 00	1	1	511 93	3575 40	1
9	2 50	0 00	0 19	22500 00	1	1	483 23	3122 22	1
10	2 33	0 00	0 19	21000 00	1	1	454 32	2700 93	1
11	2 17	0 00	0 19	25500 00	1	1	425 20	2311 32	1
12	2 00	0 00	0 19	21000 00	1	1	395 84	1953 16	1
13	1 83	0 00	0 19	24000 00	1	1	366 21	1626 23	1
14	1 67	0 00	0 19	22500 00	1	1	336 30	1330 27	1
15	1 50	0 00	0 19	21000 00	1	1	306 07	1065 00	1
16	1 33	0 00	0 19	19500 00	1	1	275 48	830 12	1
17	1 17	0 00	0 19	22500 00	1	1	244 48	625 29	1
18	1 00	0 00	0 19	18000 00	1	1	213 01	450 14	1
19	0 83	0 00	0 19	22500 00	1	1	180 97	318 72	1
20	0 67	0 00	0 19	24000 00	1	1	148 24	209 94	1
21	0 50	0 00	0 19	22500 00	1	1	114 62	124 08	1
22	0 33	0 00	0 19	21000 00	1	1	79 77	61 53	1
23	0 17	0 00	0 19	25500 00	1	1	42 93	22 88	1
24	0 00	0 00	0 19	21000 00	1	1	0 28	29 23	1

Concentration profile at 60 0 min

1	[Recp coordinates	500 00	0 00	0 00]	cr(microgm/cu m)	475 14
2	[Recp coordinates	1000 00	0 00	0 00]	cr(microgm/cu m)	280 19
3	[Recp coordinates	1000 00	50 00	0 00]	cr(microgm/cu m)	271 26
4	[Recp coordinates	1000 00	-50 00	0 00]	cr(microgm/cu m)	271.26
5	[Recp coordinates	1000 00	0 00	50 00]	cr(microgm/cu m)	285 65
6	[Recp coordinates	1000 00	0 00	75 00]	cr(microgm/cu m)	287 07
7	[Recp coordinates	1500 00	0 00	0 00]	cr(microgm/cu m)	95 61
8	[Recp coordinates	2000 00	0 00	0 00]	cr(microgm/cu m)	43.43
9	[Recp coordinates	3500 00	0 00	0 00]	cr(microgm/cu m)	6.53
10	[Recp coordinates	4500 00	0 00	0 00]	cr(microgm/cu m)	1.22

Sample Output File of SEGMNT

Plume profile at 30 0 min

Seg No	End Point coordinates(km)		Seg Mass (gm)	Rectangle #		sigmay <----(m)----->	sigmaz	ISC Stb Cls
1	2 00	0.00	0 19 24000 00	1	1	395 84	1953 16	1
2	1.83	0.00	0 19 22500 00	1	1	366 21	1626 23	1
3	1.67	0 00	0.19 21000.00	1	1	336 30	1330 27	1
4	1.50	0.00	0.19 19500 00	1	1	306 07	1065 00	1
5	1.33	0 00	0.19 22500.00	1	1	275 48	830.12	1
6	1 17	0.00	0 19 18000 00	1	1	244 48	625 29	1
7	1 00	0.00	0 19 22500.00	1	1	213 01	450 14	1
8	0 83	0.00	0.19 24000 00	1	1	180 97	318 72	1
9	0 67	0 00	0.19 22500 00	1	1	148 24	209 94	1
10	0 50	0 00	0 19 21000 00	1	1	114 62	124.08	1
11	0 33	0 00	0.19 25500 00	1	1	79 77	61 53	1
12	0 17	0 00	0.19 21000 00	1	1	42 93	22.88	1
13	0 00	0 00	0.19	1	1	0 28	29.23	1

Concentration profile at 30 0 min

1	xr: 500.00 yr	0 00	zr: 0 00	Recp Concn	635	69801
2	xr: 1000.00 yr:	0 00	zr: 0 00	Recp Concn	306	80565
3	xr: 1000 00 yr:	50 00	zr: 0.00	Recp Concn :	298	46797
4	xr. 1000 00 yr	-50 00	zr: 0 00	Recp Concn :	298	46797
5	xr: 1000 00 yr	0 00	zr:50 00	Recp Concn :	310	08984
6	xr 1000.00 yr	0 00	zr 75 00	Recp Concn :	310	53269
7	xr: 1500 00 yr	0 00	zr: 0 00	Recp Concn '	84	30892
8	xr: 2000.00 yr:	0 00	zr: 0 00	Recp Concn :	44	25329
9	xr: 3500.00 yr:	0 00	zr: 0 00	Recp Concn :	0	00000
10	xr: 4500.00 yr	0 00	zr: 0 00	Recp Concn :	0	00000

Plume profile at 60.0 min.

Seg No	End Point coordinates(km)		Seg Mass (gm)	Rectangle #		sigmay <----(m)----->	sigmaz	ISC Stb.Cls.
1	4 00	0.00	0 19 24000 00	1	1	735 59	8370.03	1
2	3 83	0.00	0 19 22500 00	1	1	708 13	7655.55	1
3	3.67	0 00	0 19 21000.00	1	1	680 54	6974 26	1
4	3 50	0 00	0 19 19500 00	1	1	652 82	6326 03	1
5	3 33	0 00	0 19	1	1	624 96	5710 70	1

				22500 00					
6	3 17	0 00	0 19		1	1	596 94	5128 14	1
				18000 00					
7	3 00	0 00	0 19		1	1	568 78	4578 18	1
				22500 00					
8	2 83	0.00	0 19		1	1	540 44	4060 66	1
				24000 00					
9	2 67	0.00	0 19		1	1	511 93	3575 40	1
				22500 00					
10	2 50	0.00	0 19		1	1	483 23	3122 22	1
				21000 00					
11	2 33	0.00	0 19		1	1	454 32	2700 93	1
				25500 00					
12	2 17	0.00	0 19		1	1	425 20	2311 32	1
				21000 00					
13	2 00	0.00	0 19		1	1	395 84	1953 16	1
				24000 00					
14	1 83	0 00	0 19		1	1	366 21	1626 23	1
				22500 00					
15	1 67	0.00	0 19		1	1	336 30	1330.27	1
				21000 00					
16	1 50	0.00	0.19		1	1	306 07	1065 00	1
				19500 00					
17	1 33	0.00	0 19		1	1	275 48	830 12	1
				22500 00					
18	1 17	0 00	0 19		1	1	244 48	625 29	1
				18000 00					
19	1 00	0 00	0 19		1	1	213 01	450 14	1
				22500 00					
20	0 83	0 00	0 19		1	1	180 97	318 72	1
				24000 00					
21	0 67	0 00	0 19		1	1	148 24	209 94	1
				22500 00					
22	0 50	0 00	0 19		1	1	114 62	124 08	1
				21000 00					
23	0 33	0 00	0 19		1	1	79 77	61 53	1
				25500 00					
24	0 17	0 00	0 19		1	1	42 93	22 88	1
				21000 00					
25	0 00	0 00	0 19		1	1	0 28	29 23	1

Concentration profile at 60 0 min

1	xr	500 00	yr	0 00	zr	0 00	Recp Concn	635	69801
2	xr	1000.00	yr	0 00	zr	0 00	Recp Concn	306	80565
3	xr:	1000.00	yr	50 00	zr	0 00	Recp Concn	298	46797
4	xr	1000.00	yr	-50 00	zr	0 00	Recp Concn	298	46797
5	xr	1000.00	yr	0 00	zr	50 00	Recp Concn	310	08984
6	xr	1000 00	yr	0 00	zr	75 00	Recp Concn	310	53269
7	xr	1500 00	yr	0 00	zr	0 00	Recp.Concn	84	30892
8	xr	2000 00	yr	0 00	zr	0 00	Recp.Concn	. 44	25329
9	xr:	3500 00	yr:	0 00	zr:	0 00	Recp.Concn	6	76094
10	xr	4500 00	yr	0 00	zr:	0 00	Recp.Concn	0	00000

Sample Output File of PUFSEG

Plume profile at 30 0 min

Point No	End Point coordinates(km)		Ele	Mass (gm)	Rectangle #		sigmay <----(m)----->	sigmaz	ISC Stb	Cls
1	2 00	0.00	0 19	24000 00 [PUFF]	1	1	395 84	1953 16		1
2	1.83	0.00	0 19	22500 00 [PUFF]	1	1	366 21	1626 23		1
3	1 67	0 00	0 19	21000 00 [PUFF]	1	1	336 30	1330 27		1
4	1 50	0 00	0 19	19500 00 [PUFF]	1	1	306 07	1065 00		1
5	1 33	0 00	0 19	22500 00 [PUFF]	1	1	275 48	830 12		1
6	1 17	0 00	0 19	18000 00 [PUFF]	1	1	244 48	625 29		1
7	1 00	0 00	0 19	22500 00 [PUFF]	1	1	213 01	450 14		1
8	0 83	0 00	0 19	24000 00 [PUFF]	1	1	180 97	318 72		1
9	0 67	0 00	0 19	22500 00 [PUFF]	1	1	148 24	209 94		1
10	0 50	0 00	0 19	21000 00 [PUFF]	1	1	114 62	124 08		1
11	0 33	0 00	0 19	25500 00[SEGMENT]	1	1	79 77	61 53		1
12	0 17	0 00	0 19	21000 00[SEGMENT]	1	1	42 93	22 88		1
13	0 00	0 00	0 19		1	1	0 28	29 23		1

Concentration profile at 30.0 min.

1	xr	500.00	yr:	0 00	zr:	0 00	Recp.Concn :	652 595
2	xr	1000 00	yr:	0 00	zr:	0 00	Recp.Concn	288 573
3	xr	1000 00	yr:	50.00	zr:	0 00	Recp.Concn :	279 318
4	xr:	1000 00	yr:	-50 00	zr:	0 00	Recp Concn	279 318
5	xr	1000 00	yr:	0 00	zr:	50 00	Recp.Concn :	294 013
6	xr:	1000 00	yr:	0.00	zr:	75 00	Recp.Concn	295 368
7	xr	1500 00	yr:	0.00	zr:	0 00	Recp.Concn :	90 071
8	xr:	2000 00	yr:	0 00	zr	0 00	Recp.Concn	28 188
9	xr	3500 00	yr:	0.00	zr	0 00	Recp.Concn :	0 002
10	xr:	4500.00	yr	0 00	zr	0 00	Recp.Concn	0 000

Plume profile at 60.0 min

Point No	End Point coordinates(km)		Ele	Mass (gm)	Rectangle #		sigmay <----(m)----->	sigmaz	ISC Stb	Cls.
1	4 00	0 00	0 19	24000 00 [PUFF]	1	1	735 59	8370 03		1
2	3 83	0 00	0 19	22500 00 [PUFF]	1	1	708 13	7655 55		1
3	3 67	0 00	0 19	21000 00 [PUFF]	1	1	680 54	6974 26		1
4	3 50	0 00	0 19		1	1	652 82	6326 03		1

				19500 00 [PUFF]					
5	3 33	0.00	0.19	1	1	624 96	5710 70	1	
				22500 00 [PUFF]					
6	3 17	0 00	0 19	1	1	596 94	5128 14	1	
				18000 00 [PUFF]					
7	3 00	0 00	0 19	1	1	568 78	4578 18	1	
				22500 00 [PUFF]					
8	2 83	0 00	0 19	1	1	540 44	4060 66	1	
				24000 00 [PUFF]					
9	2 67	0 00	0.19	1	1	511 93	3575 40	1	
				22500 00 [PUFF]					
10	2 50	0 00	0 19	1	1	483 23	3122 22	1	
				21000 00 [PUFF]					
11	2 33	0 00	0 19	1	1	454 32	2700 93	1	
				25500 00 [PUFF]					
12	2 17	0 00	0 19	1	1	425 20	2311 32	1	
				21000 00 [PUFF]					
13	2 00	0 00	0 19	1	1	395 84	1953 16	1	
				24000 00 [PUFF]					
14	1 83	0 00	0 19	1	1	366 21	1626 23	1	
				22500 00 [PUFF]					
15	1 67	0 00	0 19	1	1	336 30	1330 27	1	
				21000 00 [PUFF]					
16	1 50	0 00	0 19	1	1	306 07	1065 00	1	
				19500 00 [PUFF]					
17	1 33	0 00	0 19	1	1	275 48	830 12	1	
				22500 00 [PUFF]					
18	1 17	0 00	0 19	1	1	244 48	625 29	1	
				18000 00 [PUFF]					
19	1 00	0 00	0 19	1	1	213 01	450 14	1	
				22500 00 [PUFF]					
20	0 83	0 00	0 19	1	1	180 97	318 72	1	
				24000 00 [PUFF]					
21	0 67	0 00	0.19	1	1	148 24	209 94	1	
				22500 00 [PUFF]					
22	0 50	0 00	0.19	1	1	114 62	124 08	1	
				21000 00 [PUFF]					
23	0 33	0 00	0 19	1	1	79 77	61 53	1	
				25500 00[SEGMENT]					
24	0 17	0 00	0 19	1	1	42 93	22 88	1	
				21000 00[SEGMENT]					
25	0 00	0 00	0 19	1	1	0 28	29.23	1	

Concentration profile at 60 0 min

1	xr	500 00	yr	0 00	zr	0 00	Recp Concn	652 602
2	xr	1000.00	yr	0 00	zr	0 00	Recp Concn	288.897
3	xr	1000 00	yr	50 00	zr	0 00	Recp Concn	279.640
4	xr	1000 00	yr	-50 00	zr	0 00	Recp Concn	279 640
5	xr	1000 00	yr	0 00	zr	50 00	Recp Concn	294.337
6	xr	1000 00	yr	0 00	zr	75 00	Recp Concn	295 692
7	xr	1500.00	yr	0 00	zr	0 00	Recp Concn	94 211
8	xr	2000 00	yr	0 00	zr	0 00	Recp Concn	42.921
9	xr	3500 00	yr	0 00	zr	0 00	Recp Concn	6 734
10	xr	4500 00	yr	0 00	zr	0 00	Recp Concn	1 399